
Event Agenda

Engineering Mechanics Institute Conference 2026

Tuesday, June 02, 2026

Workshop: The Phase-Field Approach to Fracture: Theory and Numerical Implementation

8:00 AM – 3:00 PM | Location: HUMN 150

Course Outline:

This short course will present the mathematical formulation and the associated numerical implementation of the phase-field approach to fracture. In a nutshell, the phase-field approach to fracture is the culmination of combined efforts (started at the end of the 1990s) by the mathematics and computational mechanics communities – the aim was to describe when and where a fracture nucleates and propagates in solids under arbitrary mechanical loads in a computationally tractable manner. These efforts comprise three pivotal ideas: (i) the casting of the phenomenon of fracture propagation as a variational problem [1], (ii) its regularization into second-order PDEs [2], and (iii) the generalization of these PDEs to account for fracture nucleation at large [3-5]. These ideas constitute the phase-field approach to fracture.

The literature on the phase field approach and its applications is vast, so the course will focus on the fundamental theoretical principles of the approach from a macroscopic point of view and its application to elastic brittle materials like glass, ceramics, and elastomers (generalization to ductile materials will be briefly discussed). In such materials, energy is dissipated only through the creation of new surfaces and is proportional to the area created. Three key pivotal ideas establishing this approach are: (1) fracture toughness as the proportionality constant between dissipated energy and crack surface area governs fracture nucleation and propagation from large pre-existing cracks; 2) the strength surface governs crack initiation in homogeneous domain under uniform stresses, and (3) the mediation of toughness and strength governs the crack nucleation under non-uniform stress states and weak stress singularities.

This one-day short course will include a detailed introduction to the three pivotal ideas listed above, and the constitutive choices that are made to develop a generalized phase-field model. The casting of the model in a finite element formulation will be discussed along with a live demonstration in Python (using FEniCS library [8, 9]) to solve representative boundary-value problems involving fracture nucleation and propagation in both linear elastic and hyperelastic materials. We will briefly discuss adaptive mesh refinement method in FEniCS to accelerate large computations [6, 7]. The course material will include lecture notes on the fundamentals of the method in addition to the Python codes used for the live demonstration. A Slack discussion group will be created for the workshop attendees. Helpful references are listed below.

References:

1. Francfort GA, Marigo JJ (1998) J Mech Phys Solids 46:1319–1342.
2. Bourdin B, Francfort GA, Marigo JJ (2000) J Mech Phys Solids 48:797–826.
3. Kumar A, Francfort GA, Lopez-Pamies O (2018) J Mech Phys Solids 112:523–551.
4. Kumar A, Bourdin B, Francfort GA, Lopez-Pamies O (2020) J Mech Phys Solids 142:104027.
5. Kumar A, Ravi-Chandar K, Lopez-Pamies O (2022) Int J Fract 237, 83–100.
6. Gupta A, Krishnan UM, Mandal TK, Chowdhury R, Nguyen VP (2022) Comput Methods Appl Mech Eng 399:115347.
7. Gupta A, Nguyen DT, Hirshikesh, Duddu R (2024) Eng Fract Mech 306:110252.
8. FEniCS computing platform
9. FEniCS workshop

Agenda:

Hours 1-2: The Theory

Griffith idea for fracture

Fracture propagation as a variational problem

Regularization of Griffith-type surface energy and introduction to phase-field

Euler-Lagrange equations of the variational problem

Ingredients for describing fracture nucleation at large

Concept of strength surface

Generalizing the Euler-Lagrange equations of the variational problem to account for the strength surface

Generalization to ductile fracture

Hours 3-6: The Numerical Implementation

Weak form and finite element formulation of the PDEs

Staggered formulation for solving coupled PDEs

Choice of regularization length scale, mesh size, irreversibility

Calibration of toughness and strength parameters

Adaptive mesh refinement

Representative boundary-value problems:

Double cantilever beam problem for fracture propagation

Nucleation under torsion

Nucleation in Brazilian fracture test

Indentation problem with a cylindrical indenter

Mixed-mode propagation in bending experiments

Dynamic branching test

Nucleation and propagation in an elastomeric specimen

Thermal quenching of a plate

Speakers



Aditya Kumar

Assistant Professor | Georgia Institute of Technology



Abhinav Gupta

Research Assistant Professor | Vanderbilt University



Ravindra Duddu

Associate Professor | Vanderbilt University

Board of Governors Meeting

8:00 AM – 1:30 PM | Location: Limelight - Bear Peak

Board and Chair Meeting (invitation only)

1:30 PM – 2:30 PM | Location: Limelight - Bear Peak

Registration

1:30 PM – 6:00 PM | Location: Limelight - Flatirons Foyer

Objective Resilience committee meeting

2:30 PM – 3:30 PM | Location: Limelight - Royal Arch

Architected Materials committee meeting

3:00 PM – 4:00 PM | Location: Limelight - Bear Peak

Fluid Dynamics committee meeting

3:00 PM – 4:00 PM | Location: Limelight - Trailhead

Dynamics committee meeting

3:00 PM – 4:00 PM | Location: Limelight - Flatirons 3

Machine Learning committee meeting

3:00 PM – 4:00 PM | Location: Limelight - Flatirons 4

Elasticity committee meeting

3:00 PM – 4:00 PM | Location: Limelight - Meadows A

Modeling Inelasticity & Multiscale Behavior committee meeting

3:00 PM – 4:00 PM | Location: Limelight - Meadows B

Granular Materials committee meeting

3:00 PM – 4:00 PM | Location: <https://northwestern.zoom.us/j/2188987153>

Poromechanics committee meeting

3:30 PM – 4:30 PM | Location: Limelight - Royal Arch

Mentoring and Early Career Advancement committee meeting

3:30 PM – 4:30 PM | Location: Limelight - Meadows C&D

Computational Mechanics committee meeting

4:00 PM – 5:00 PM | Location: Limelight - Bear Peak

Structural Stability committee meeting

4:00 PM – 5:00 PM | Location: Limelight - Trailhead

Structural Health Monitoring and Control committee meeting and student competition

4:00 PM – 6:00 PM | Location: Limelight - Flatirons 3

Experimental Analysis & Instrumentation committee meeting and student competition

4:30 PM – 6:00 PM | Location: Limelight - Royal Arch

Probabilistic Methods committee meeting

4:30 PM – 6:00 PM | Location: Limelight - Flatirons 4

Nanomechanics and Micromechanics committee meeting

5:00 PM – 6:00 PM | Location: Limelight - Bear Peak

Biomechanics committee meeting

5:00 PM – 6:00 PM | Location: Limelight - Trailhead

Welcome Reception

6:00 PM – 8:30 PM | Location: Limelight - Viewpoint Deck / The Lawn

Wednesday, June 03, 2026

Breakfast

7:00 AM – 7:50 AM

Buffet-style breakfast

7:00 AM – 7:50 AM

Light breakfast

7:30 AM – 7:50 AM

Breakfast will be served until 9am.

Registration

7:30 AM – 6:00 PM | Location: UMC - Aspen Rooms

Opening Remarks

8:00 AM – 8:10 AM | Location: UMC - Glenn Miller Ballroom

Keynote: Engineering Origami Structures and Metamaterials

8:10 AM – 9:10 AM | Location: UMC - Glenn Miller Ballroom

Engineering Origami Structures and Metamaterials

Glaucio H. Paulino, Ph.D., NAE, F.EMI, M.ASCE

Margareta E. Augustine Professor of Engineering

Princeton University

Abstract: Metamaterials with multimodal deformation mechanisms resemble machines, especially when endowed with autonomous functionality. A representative architected assembly, with tunable chirality, converts linear motion into rotation. These chiral systems with a machine-like dual modality have potential use in areas such as wave manipulation, optical activity related to circular polarization and chiral active fluids. However, in previous literature, the dual motions are essentially coupled and cannot be independently controlled. Moreover, they are restricted to small deformations, which limits their applications. We use a ground-structure based topology optimization formulation to establish modular chiral structures and metamaterials, consisting of auxetic planar tessellations and origami-inspired columnar arrays, with decoupled actuation. Under single-degree-of-freedom actuation, the assembly twists between 0° and 90°, contracts in-plane up to 25% and shrinks out-of-plane more than 50%. Using experiments and simulations, we show that the deformation of the assembly involves in-plane twist and contraction dominated by the rotating-square tessellations and out-of-plane shrinkage dominated by the tubular Kresling origami arrays. Moreover, we demonstrate two distinct actuation conditions: twist with free translation and linear displacement with free rotation. Our metamaterial is built on a highly modular assembly, which enables reprogrammable instability, local chirality control, tunable loading capacity and scalability. Our concept provides routes towards multimodal, multistable and reprogrammable machines, with applications in robotic transformers, thermoregulation, mechanical memories in hysteresis loops, non-commutative state transition and plug-and-play functional assemblies for energy absorption and information encryption.

Biosketch: Professor Paulino is the Margareta E. Augustine Professor of Engineering at Princeton University. He is a member of the US National Academy of Engineering (NAE) and European Academy of Sciences and Arts (EASA). His seminal contributions include the development of methodologies to characterize the deformation and fracture behavior of existing and emerging materials; topology optimization for large-scale multiscale/multiphysics problems; variational methods; deployable and adaptable structures; and origami

engineering (topic of his lecture at the EMI CONFERENCE).

He is a fellow of all major professional societies, including EMI, ASME (American Soc. of Mechanical Engineers), AAM (American Academy of Mechanics), SES (Society of Engineering Science), ISSMO (International Society for Structural & Multidisciplinary Optimization), USACM (US Association for Computational Mechanics), IACM (International Association for Computational Mechanics).

He received the Mindlin Medal of ASCE, the Drucker Medal and the Melville Medal of ASME, the Eringen Medal from SES, the Reddy Medal from Mechanics of Advanced Materials and Structures, and the Belytschko Medal twice, one from ASME and one from USACM. He also received the 2015 Cozzarelli Prize from the National Academy of Sciences, "which recognizes recently published PNAS papers of outstanding scientific excellence and originality."

Speaker



Glaucio H. Paulino

Margareta E. Augustine Professor of Engineering | Princeton University

Moderators



Mija Hubler

Associate Professor | University of Colorado Boulder

Coffee Break

9:10 AM – 9:30 AM | Location: UMC - Aspen Rooms & UMC - 235

MS 007: Advances in Computer Vision, Deep Learning, & Artificial Intelligence for Structural Monitoring, Inspections, and Digital Twins

9:30 AM – 11:30 AM | Location: HUMN 250

Chair(s): Vedhus Hoskere; Mohammad Jahanshahi; Jian Li; Wei Song

Moderatorss



Vedhus Hoskere

Assistant Professor | University of Houston



Jian Li

Deane E. Ackers Professor | University of Kansas

ID 60: Improved vision transformer for post disaster damage classification

9:30 AM – 9:50 AM

Author(s): Carlos Canchila, University of Alabama; Wei Song, University of Alabama

Accurate and rapid damage assessment after a disaster is critical to mitigate the negative impact of the event and support effective response efforts. Yet, current damage assessment is labor-intensive and time-consuming, motivating the adoption of deep learning techniques for automated analysis. In recent years, vision transformers (ViTs), a type of deep learning technique, have gained increasing attention as a promising approach for damage assessment through classification of damage on images. Thanks to the self-attention mechanism, ViTs have demonstrated outstanding performance across a wide range of computer vision tasks. However, several architectural limitations restrict the direct applicability of conventional ViTs for damage classification, including the lack of multi-scale feature extraction and heavy dependence on large amounts of training data. In this research, a novel ViT architecture for damage classification is designed to overcome these limitations. This proposed ViT introduces enhanced attention mechanisms for robust feature understanding. Furthermore, pretraining strategies are evaluated to overcome the data scarcity limitation and improve model performance. The proposed ViT is trained and tested on a disaster damage dataset collected by the authors. Comparative studies are conducted to evaluate the performance of the proposed ViT against existing state-of-the-art ViTs. The results demonstrate that the proposed architecture improves damage classification accuracy, while also providing valuable insights into addressing the challenges associated with complex disaster scene analysis.

Speaker



Carlos Andres Canchila Martinez

Ph.D. candidate | The University of Alabama

ID 329: CycleGAN-Based Unsupervised Shadow Removal for Pavement Crack Detection Enhancement

9:50 AM – 10:10 AM

Author(s): Ming-Shi Tsai, National Yang Ming Chiao Tung University; Yu-Ting Huang, National Yang Ming Chiao Tung University; Mohammad Reza Jahanshahi, Purdue University

Accurate pavement crack detection is essential for reliable pavement condition assessment and maintenance prioritization. However, in real-world roadway, shadows cast by vehicles, utility cables, and roadside trees often create visual patterns that similar to pavement distresses. Linear shadows from cables or tree are commonly misclassified as cracks. Complex shadows formed by tree branches and dense shadows cast by vehicles are often mistaken for alligator cracking or potholes. These shadow-induced false positives undermine automated inspection results and lead to inaccurate pavement condition assessments and suboptimal maintenance decisions.

Shadow-induced appearance variations are difficult to handle using conventional image processing approaches, as simple threshold-based methods cannot adapt to spatially varying illumination and texture changes. Generative Adversarial Networks (GAN) are widely used for image-to-image translation tasks, such as style transfer and appearance transformation. This is because they can learn complex visual mappings directly from data. This capability makes GAN-based models particularly suitable for shadow removal. The objective of the proposed work is to eliminate shadows while preserving the underlying pavement texture and crack patterns.

Although supervised shadow removal approaches have demonstrated effectiveness, their reliance on paired shadow and shadow-free image datasets severely limits practical deployment. In real-world roadway, collecting paired pavement crack images under identical viewpoints with and without shadows is barely feasible, as lighting conditions vary continuously throughout the day. Achieving pixel-level correspondence between shadowed and non-shadowed images is therefore extremely challenging and time-consuming, making such datasets difficult to obtain at scale.

To overcome this limitation, an unsupervised shadow removal framework is developed based on CycleGAN. The model enables unpaired image-to-image translation through cycle-consistency constraints, allowing it to learn shadow to shadow-free mappings from independent sets of shadowed and non-shadowed pavement images. The framework is trained on a self-collected unpaired pavement dataset. Preserving fine-scale crack features remains difficult, especially when cracks are partially or fully obscured by shadows. Standard adversarial and cycle-consistency losses often lead to over-smoothing, texture distortion, or the unintended removal of true crack structures. To address this issue, modified loss functions are introduced. First, a perceptual loss is employed to preserve high-level structural information and maintain crack continuity. Next, a smoothness loss is applied to reduce visual inconsistencies and abrupt intensity transitions near shadow boundaries, which commonly degrade segmentation performance. Lastly, a physics-informed reflectance loss constrains illumination correction by enforcing consistency in surface reflectance, assuming that pavement material properties remain unchanged under varying lighting conditions. This loss helps decouple illumination effects from intrinsic pavement texture, preventing unrealistic brightness changes after shadow removal. Together, these losses balance effective shadow suppression with crack feature preservation.

The proposed framework is evaluated through comprehensive experiments and ablation studies. A crack segmentation baseline is first trained using the public Crack500 dataset, and detection performance is compared on raw shadow-affected images and shadow-removed images. Additional retraining experiments using integrated datasets demonstrate that the proposed method consistently maintains crack detection accuracy under complex lighting conditions. The results indicate that the proposed shadow removal approach improves the robustness and reliability of automated pavement inspection systems in real-world environments.

Speaker



MingShi Tsai

graduate student | National Yang Ming Chiao Tung University

ID 492: Toward Smart Structural Inspections: Merging ARKit, LiDAR, and YOLOv8 on iOS

10:10 AM – 10:30 AM

Author(s): Chia-Ming Chang, National Taiwan University; Yen-Teng Chang, National Taiwan University

Traditional visual inspections for structural damage remain essential yet inefficient, often requiring labor-intensive efforts, subjective judgment, and time-consuming documentation. These limitations are amplified in rapidly urbanizing environments with aging infrastructure and a shortage of qualified engineers. To address these challenges, this research presents the development of a mobile-based inspection tool that integrates augmented reality and machine learning into a seamless, real-time workflow on iOS devices. Built using Apple's ARKit and RoomPlan frameworks, the tool leverages LiDAR-equipped devices to create accurate 3D spatial reconstructions of indoor environments. This AR-based mapping is combined with YOLOv8, a state-of-the-art real-time object detection model, which is optimized and converted to Apple's Core ML format for on-device processing. During inspection, the system enables users to scan indoor spaces, detect structural defects (e.g., cracks, spalling) in real time, and anchor those defects spatially within the 3D model. A raycasting mechanism enables precise localization, while 2D floor plans and defect metadata are automatically generated for post-inspection analysis. Field tests conducted across various interior environments demonstrate significant reductions in inspection time, improved accuracy in defect measurement, and enhanced documentation reliability compared to traditional methods. The app also enables seamless export of 3D models, annotated images, and floor plans, streamlining report generation and reducing reliance on post-processing tools such as AutoCAD. This work highlights the potential of integrating AR and ML into mobile platforms to create smarter, more scalable inspection systems. The development offers a replicable, cost-effective framework for transforming visual inspections in structural engineering, particularly in resource-constrained or high-demand urban settings. Future work will focus on expanding the defect categories, improving model robustness, and automating the generation of full inspection reports on-device.

Speaker



Chia-Ming Chang

Professor | National Taiwan University

ID 498: Automated Structural Assessment and Tilt Measurement of Coastal Utility Poles: Leveraging Human-Refined Grounded SAM 3 and LiDAR Integration

10:30 AM – 10:50 AM

Author(s): Jangjae Lee, University of Houston; Abigail Beck, University of Houston

Coastal utility networks function as critical electricity distribution infrastructure, which can be susceptible to structural instabilities resulting from intense weather patterns and gradual ground degradation. Maintaining the structural integrity of these networks—comprising legacy timber and pre-stressed concrete (PSC) utility poles—is a significant factor in grid resilience, yet consistent monitoring remains a labor-intensive and logistically challenging task. This study introduces an automated sensing framework that leverages Grounded SAM 3 for rapid utility pole detection, with Light Detection and Ranging (LiDAR) to enable high-precision tilt calculation and structural integrity assessment.

The methodology follows a systematic "Calibration-to-Scale" pipeline designed to optimize model performance across different geographic conditions. In the initial phase, Grounded SAM 3 is utilized to generate preliminary semantic labels for utility poles from mobile imagery. To ensure data reliability, a human-mediated refinement step is implemented to verify asset presence and filter out non-target objects, resulting in a high-quality curated dataset. This refined dataset serves as the foundation for a specialized structural assessment framework. Rather than focusing solely on object detection, this framework integrates 3D spatial intelligence validated against the Houston-Galveston region LiDAR data to establish a rigorous baseline for automated tilt measurement consistency.

Building on this foundation, the framework is designed to be scaled for deployment across the Galveston, Texas corridor to evaluate its regional applicability. While exhaustive LiDAR verification can be cost-prohibitive for vast distribution networks, the strategic transfer of human-refined weights is intended to enable high-throughput, automated tilt estimation in new environments with minimal manual oversight. By quantifying angular deviations, the system is structured to facilitate the categorization of assets into a multi-tier risk hierarchy, supporting a potential transition from reactive repair cycles toward more proactive, data-driven maintenance strategies. Ultimately, this approach seeks to deliver a quantified risk profile for coastal grids, strengthening the systemic resilience of essential infrastructure against evolving environmental hazards.

Speaker



Jangjae Lee

Postdoctoral Fellow | University of Houston

ID 580: A Multi-Attention Vision Framework for Standards-Aligned Steel Bridge Corrosion Assessment

10:50 AM – 11:10 AM

Author(s): Yao-Teng (Ted) Hu, Zachry Department of Civil and Environmental Engineering, Texas A & M University, College Station, 77843, Texas, USA.; Jian Tao, College of Performance, Visualization & Fine Arts, Texas A & M Institute of Data Science (TAMIDS), College Station, 77843, TX, USA; Arash Noshadravan, Zachry Department of Civil and Environmental Engineering, Texas A & M University, College Station, 77843, Texas, USA.

This work introduces a specialized, standards-grounded AI system for accurate, component-aware detection of active corrosion in steel bridges, bridging the gap between subjective manual observations and verifiable engineering standards. Visual inspection of steel bridges remains a labor-intensive process plagued by inherent subjectivity. Human cognitive biases significantly compromise inspection reliability, creating a persistent gap between on-site observations and auditable engineering standards. Consequently, Computer Vision (CV) has been widely adopted to mitigate this human subjectivity and improve objectivity. However, this shift necessitates a critical examination of algorithmic limitations. While modern AI promises automation, current state-of-the-art technologies—specifically general-purpose Vision-Language Models (VLMs)—are fundamentally unreliable for high-stakes structural analysis. Recent applications of general-purpose VLMs reveal a critical failure mode, namely attention contamination, in which active corrosion on steel members is consistently confused with visually similar background artifacts, such as rust staining on concrete piers or weathering steel patina.

To address these limitations, the primary objective of this research is to establish a robust framework for automated, component-constrained corrosion assessment. The proposed system simultaneously characterizes structural geometry and active corrosion, ensuring that defect detection is strictly constrained to valid bridge components and effectively distinguished from background noise. By filtering out environmental distractors, the framework produces verified, pixel-level corrosion maps that provide a quantitative basis for accurate condition evaluation and auditable, standards-consistent decision-making.

To achieve this, we propose a three-stage, standards-aligned methodology that constructs a specialized visual agent tailored to steel bridge assets. First, we address data scarcity by constructing the SCD-2K (Structural Corrosion Dataset) using a VLM-assisted human-in-the-loop pipeline, providing high-resolution imagery with pixel-level annotations of both structural components and active corrosion. Second, leveraging this dataset, we develop a Dual-Attention Transformer Model that explicitly decouples structural geometry from corrosion texture and enforces a programmatic gating mechanism to eliminate background-induced false positives, yielding verified corrosion masks robust to attention contamination. Third, these verified masks are used as trusted queries for a clause-granular retrieval-augmented generation (RAG) engine that retrieves authoritative provisions from standards such as ASTM D610 and AASHTO to produce explainable, evidence-linked inspection reports. Together, this integrated vision–reasoning pipeline enables auditable, standards-consistent corrosion assessment suitable for automated bridge asset management.

Speaker



Yao Teng Hu

PhD student | Texas A&M University

ID 722: Bridging Local Details and Global Context for Vision-Based Corrosion Segmentation Using Transformer-CNN Hybrid Architecture

11:10 AM – 11:30 AM

Author(s): Abhishek Subedi, Purdue University; Mohammad Jahanshahi, Purdue University

Automated corrosion assessment from visual data has emerged as a critical component of modern structural health monitoring, particularly for metallic infrastructure that is difficult, hazardous, or costly to inspect manually. While Convolutional Neural Networks (CNNs) have demonstrated strong performance in pixel-level corrosion segmentation due to their local inductive biases, they often struggle to incorporate long-range contextual information. Conversely, Transformer-based vision models excel at global reasoning but may underperform when fine-grained local texture is essential, as is the case for corrosion patterns. This paper presents a hybrid segmentation framework that integrates the complementary strengths of CNNs and Transformers to achieve robust, real-time corrosion segmentation on complex metallic surfaces. The proposed approach employs a dual-branch encoder that processes input imagery through parallel convolutional and attention-based pathways. The convolutional branch emphasizes localized texture and edge information characteristic of corrosion, while the Transformer branch captures global semantic relationships across the scene. To effectively reconcile the heterogeneous feature representations produced by these two paradigms, we introduce a lightweight feature alignment mechanism that adaptively harmonizes channel-wise semantics during multi-scale fusion. This design mitigates representational incompatibility between convolutional and attention-derived features, enabling coherent downstream decoding. A hierarchical decoder is used to progressively reconstruct segmentation masks across multiple spatial resolutions, allowing the network to simultaneously preserve fine boundary details and coarse contextual structure. The overall architecture is optimized for both accuracy and computational efficiency, making it suitable for deployment in real-world inspection workflows, including robotic and aerial data collection platforms. Extensive experiments are conducted on a diverse corrosion image dataset characterized by significant class imbalance and challenging backgrounds. Performance is evaluated using multiple complementary metrics, including precision, recall, F-score, and Intersection over Union (IoU), across repeated cross-validation and Monte Carlo data splits. The proposed hybrid model consistently outperforms representative CNN-based and Transformer-based segmentation baselines, achieving an average IoU improvement of up to 2-3% over the strongest competing methods while maintaining real-time inference speeds. Statistical significance testing confirms that these performance gains are robust and not attributable to sampling variability. Ablation studies further demonstrate the necessity of hybrid feature extraction and semantic alignment for optimal performance. These results suggest that explicitly combining local and global visual reasoning within a unified segmentation architecture offers a practical and effective solution for automated corrosion inspection, with implications for scalable infrastructure monitoring and maintenance decision-making.

Speaker



Abhishek Subedi

Research Assistant | Purdue University

MS 004: Computer vision and vibration-based damage identification using machine and deep learning

9:30 AM – 11:30 AM | Location: HUMN 135

Chair(s): YoungJin Cha; Oral Buyukozturk

Moderators



Youngjin Cha

Professor, F.ASCE, HCR | University of Manitoba

ID 386: Deep learning-based structural health monitoring

9:30 AM – 9:50 AM

Author(s): YoungJin Cha, University of Manitoba; Oral Buyukozturk, Massachusetts Institute of Technology

This abstract presents a comprehensive review of deep learning (DL)-based structural health monitoring (SHM), encompassing a wide spectrum of theories, methodologies, and applications since 2017. DL has demonstrated remarkable capabilities in extracting robust features from diverse data sources acquired via various sensing modalities, stimulating substantial research interest in SHM. The review systematically covers nondestructive evaluation (NDE) techniques, computer vision-based methods, digital twins, unmanned aerial vehicles (UAVs), and their integration with DL. It also examines vibration-based strategies, including sensor fault detection and data recovery, as well as physics-informed DL approaches. Connections between traditional machine learning and DL-based methods, and the interplay between local and global monitoring strategies, are established to illustrate the evolution of SHM practices and their integration.

State-of-the-art DL methods for SHM are discussed in detail, highlighting their advantages, limitations, and progression over time. Early applications relied on relatively shallow convolutional neural networks (CNNs) for binary classification tasks, such as crack detection in images. These networks were subsequently extended to detect diverse damage types, including deformations, mold, and material deterioration, and integrated with UAV-based inspection systems for automated monitoring. CNNs have also been applied to vibration-based damage detection by converting 1D time-series data into 2D representations via Fourier or wavelet transforms, enabling robust feature extraction despite noise and environmental variability.

Advances in deep networks, including object detection models (e.g., faster R-CNN, SSD, YOLO), have enabled multi-damage detection and localization. Deep autoencoder-decoder networks, such as FCN and UNet, have facilitated pixel-wise damage segmentation in computer vision-based SHM. Recent architectures, including CrackNet, SDDNet, and STRNet, have incorporated lightweight designs, attention mechanisms, and optimized convolutional modules to allow real-time, high-resolution processing with significantly fewer parameters, improving both computational efficiency and training requirements. DL models have also been extended to vibration-based SHM using LSTM, RNN, and hybrid networks to capture nonlinear, nonstationary spatiotemporal features in complex structural responses.

Emerging methods are increasingly focused on integrating DL with high-resolution 3D digital twins through photogrammetry and laser scanning, enhancing visualization and mapping of structural damage. Hybrid approaches, combining local and global methods across multiple DL frameworks, have demonstrated improved accuracy, robustness, and resilience in structural damage detection and response prediction. However, performance remains dependent on data quality, availability, and computational cost, underscoring the need for further research in scalable, cost-effective, and generalizable SHM solutions.

Overall, this review identifies that despite rapid technological advancements, DL-based SHM remains in its early stages, with enormous potential to transform SHM into a widely deployable, automated, and reliable technology. The insights presented herein provide a holistic foundation for researchers and practitioners seeking to understand current trends, limitations, and future directions in DL-based SHM.

Speaker



Youngjin Cha

Professor, F.ASCE, HCR | University of Manitoba

ID 292: Damage Estimation to Enhance Micro-Damage Detection in Scaffolding Steel Pipes Using a Portable MFL Sensor

9:50 AM – 10:10 AM

Author(s): Hansun Kim, Sungkyunkwan University; Taeheon Kim, Sungkyunkwan University; Soojung Shin, Sungkyunkwan University; Sung-Han Sim, Sungkyunkwan University; Seunghee Park, Sungkyunkwan University

This study developed a portable magnetic flux leakage (MFL)-based nondestructive testing (NDT) device to reliably diagnose micro-defects that may occur during the reuse of temporary construction materials in the field. First, a portable MFL sensor head was designed considering the geometry of scaffolding components, and 2D/3D magnetic simulations were conducted to determine the yoke configuration, magnetization module, sensor arrangement, and lift-off conditions. The sensor head was fabricated by integrating DRV5055 Hall sensors and neodymium permanent magnets, and a portable MFL device was realized by combining the sensor head and display into a single unit, enabling defect measurement and immediate on-site result visualization through simple scanning.

For quantitative estimation of defect location and size, the denoised signal was represented as multi-channel time-series features consisting of a filtered signal, Hilbert envelope, and gradient signal, which were fed into a 1D-CNN-Transformer regression model. The 1D-CNN extracts local waveform characteristics near defects, while the Transformer captures long-range patterns across the entire scan to improve robustness under noisy conditions. Heteroscedastic regression was employed to simultaneously predict defect width and associated uncertainty, and high-uncertainty cases were automatically flagged to support re-measurement, enhancing reliability and field usability.

Experiments were conducted using specimens with through-wall defects of 0.5–3.0 mm in width. The proposed approach achieved an MAE of 0.128 mm and an RMSE of 0.159 mm over all defects; notably, for widths ≥ 2.0 mm, the MAE remained below 0.12 mm, demonstrating sufficient quantitative separability relative to defect-grade intervals. Compared with baseline models, the proposed model provided the best performance in terms of estimation accuracy and prediction stability, and the uncertainty-based decision process effectively distinguished defect-free signals that were otherwise misclassified as defective. These results verify that the proposed portable MFL sensor-based micro-damage detection and defect estimation framework is applicable to on-site quality inspection of reusable temporary construction materials and offers practical scalability.

Speaker



Hansun Kim

South Korea / Sungkyunkwan University

ID 372: Monocular vision-based depth estimation using self-supervised deep learning for infrastructure inspection

10:10 AM – 10:30 AM

Author(s): Kalena Chernesky, University of Manitoba; YoungJin Cha, University of Manitoba

Monocular vision-based depth estimation has emerged as a promising alternative to sensor-heavy solutions for three-dimensional scene understanding, enabling scalable deployment in applications where cost, hardware complexity, and data availability are limiting factors. In the context of infrastructure inspection, estimating the geometric structure of road surface damage, such as potholes, is essential for assessing damage severity, prioritizing maintenance, and supporting data-driven asset management. While recent advances in deep learning have significantly improved depth prediction performance on general benchmarks, most existing methods are developed for broad scene understanding and are not explicitly designed for fine-grained geometric analysis of localized surface degradation.

This work investigates self-supervised monocular depth estimation for pothole analysis using heterogeneous monocular imagery captured from varying viewpoints. Self-supervised learning frameworks reduce reliance on dense ground-truth depth annotations by exploiting photometric consistency and geometric relationships across image observations, making them well suited for large-scale, real-world data collection. However, monocular depth estimation inherently suffers from scale ambiguity and sensitivity to viewpoint and appearance variation. These challenges are further amplified in road scenes characterized by low texture, specular materials, dynamic illumination, and irregular surface deformation.

The proposed research explores geometry-aware self-supervised depth estimation approaches aimed at recovering stable and meaningful depth structure in damaged road regions. By examining how self-supervised depth representations respond to pothole-specific geometry, this study seeks to characterize the extent to which relative depth cues and structural consistency can be leveraged for fine-scale surface assessment. Particular attention is given to the role of geometric priors, architectural design choices, and training objectives in improving robustness under varying imaging conditions.

Rather than proposing a fully engineered inspection system, this work focuses on developing a principled understanding of the capabilities and limitations of self-supervised monocular depth estimation for infrastructure analysis. Expected contributions include identification of failure modes specific to pothole geometry, evaluation of depth stability in damaged regions, and assessment of practical considerations such as scalability and computational efficiency. By grounding monocular depth estimation in an application-driven setting, this study aims to bridge the gap between generic depth estimation research and real-world infrastructure inspection scenarios.

Speaker



Kalena Chernesky

MSc Student | University of Manitoba

ID 397: Structural Damage Identification in Railroad Bridges Combining Multi-modal Information with Physics-informed Machine Learning

10:30 AM – 10:50 AM

Author(s): Althaf Shajihan, San Diego State University

Railroad bridges are a critical part of the U.S. freight transportation network, carrying more than 40 percent of the nation's freight traffic. Many of these bridges are aging steel structures that have been in service for decades while being subjected to increasing axle loads and traffic demands. Despite their importance, early detection of structural damage remains difficult due to sparse instrumentation, limited access to bridge sites, and the short-duration nature of train crossings. These challenges are further complicated by the linear time-varying behavior of the coupled train-bridge system, which limits the effectiveness of both traditional model-based approaches and purely data-driven methods.

This study presents a physics-informed machine learning framework for damage identification in railroad bridges that integrates multi-modal information collected during in-service train operations. The proposed approach combines train wheel load data, measured bridge dynamic responses, inspection-informed prior knowledge, and physics-based structural models within a unified physics-informed neural network (PINN) framework. By embedding the governing equations of motion of the train-bridge interaction system directly into the learning process, the method enables damage-sensitive model updating without relying on labeled damage data, which are rarely available for in-service bridges.

An unsupervised learning strategy is used to leverage response data recorded during routine train crossings. The PINN architecture is formulated using a recurrent neural network with a custom Runge-Kutta integration scheme, allowing the model to capture transient dynamics induced by moving loads. Damage is inferred here through changes in learned stiffness-related parameters, with additional constraints introduced as available using prior information from inspections and baseline finite element models to reduce false-positives.

The framework is demonstrated through a case study on a full-scale steel railroad truss bridge in Chicago, Illinois, using simulated damage scenarios representative of stiffness loss in critical members. Results show that the proposed method can accurately localize and quantify damage using limited sensing data while remaining robust to operational variability. Overall, the study highlights the potential of physics-informed machine learning to enable scalable, data-efficient, and context-aware condition assessment of aging railroad bridges by integrating sensor data, inspection insights, drone-collected data and physics-based model priors.

Speaker



Althaf Shajihan

Assistant Professor | San Diego State University

ID 433: Deep Learning Enabled Vision and Inertial Fusion for Railway Track Geometry

10:50 AM – 11:10 AM

Author(s): Chang Liu, Texas A&M University; Amirali Najafi, Texas A&M University

Rail transit agencies need reliable, up-to-date information about track condition, yet existing inspection approaches often force a tradeoff between accuracy, cost, and inspection frequency. Dedicated geometry vehicles provide high-quality measurements but are expensive and typically deployed infrequently, allowing geometry problems to develop between runs. To address this gap, this work presents a compact, low-cost Rail Integrity and Geometry Sensor (RIGS) module that mounts on an inspection vehicle and integrates synchronized computer vision and inertial measurements to estimate key geometry features.

RIGS integrates a camera, inertial measurement units (IMUs), and light detection and ranging (LiDAR) within a time synchronized acquisition and processing workflow. A deep learning vision pipeline isolates the track region using a U-Net segmentation convolutional neural network and detects rail features using a pre-trained line detection model. A homography based transformation rectifies each frame to a top-down view for metric conversion and continuous geometry measurement. In parallel, the inertial channel estimates vertical displacement by bias removal, double integration of vertical acceleration, and high pass filtering to mitigate low frequency drift. The camera and IMU displacement histories are time aligned using normalized cross correlation and fused using a particle filter to combine complementary strengths. The camera provides drift free low frequency motion, while the IMU captures high frequency dynamic content but is more susceptible to low frequency drift. For vertical misalignment in the presence of structural deflection, a deflection compensation formulation combines camera based relative rail motion with IMU based absolute cart motion while accounting for the camera look ahead distance.

The approach was evaluated on a full scale 80-foot research test track with timber and concrete ties, including curvature and superelevation, and benchmarked using professional LiDAR point clouds. Field results demonstrate strong overall performance, with gauge profiles agreeing well with LiDAR derived values and curvature, vertical misalignment, and superelevation capturing global geometric trends consistently across the test section. Residual superelevation bias will be addressed through ongoing calibration and processing refinements. Future work will transition the workflow to an operational system for routine field deployment.

Speaker



Chang Liu

Research assistant | Texas A&M University

ID 991: Occlusion-Robust Computer Vision Framework for Finite Element-Compatible Digital Twins

11:10 AM – 11:30 AM

Author(s): Robin Eunju Kim, Seoul National University; Jun-Yong Lee, Seoul National University

Digital twins have become a key enabler for effective structural maintenance and health monitoring by supporting condition assessment, performance evaluation, and data-driven decision making throughout the service life of structures. Recent advances in computer vision have further accelerated digital twin generation by enabling efficient geometry acquisition through vision-based techniques such as scan-to-BIM and point cloud reconstruction. Despite these advances, two fundamental limitations hinder the practical use of vision-based digital twins for maintenance-oriented applications. First, visual occlusion in real-world environments leads to incomplete and fragmented geometric reconstructions, particularly in dense or operational structures. Second, most existing digital twins remain disconnected from finite element (FE) analysis frameworks or rely on idealized, design-stage models that fail to reflect the current structural state, limiting their usefulness for structural evaluation and maintenance decision support. This study presents a computer vision-enabled digital twin framework that explicitly addresses these limitations to generate FE-ready structural models. To overcome visual occlusion, the proposed approach leverages geometric priors from structurally similar members to extend partially observed frames and systematically complete missing point cloud regions, preserving member topology and load-carrying continuity. Furthermore, to reflect the current structural configuration in numerical analysis, joint eccentricities are explicitly identified and embedded into the FE model, capturing non-concurrent member connections that are commonly overlooked in idealized representations. While the framework operates within an IFC-based environment and utilizes large language models to extract analysis-relevant information from complex BIM data, the core contribution lies in the computer vision-driven integration of occlusion-robust geometry reconstruction and state-aware FE model generation. The proposed approach demonstrates how computer vision can play a central role in transforming visually incomplete data into structurally meaningful digital twins for maintenance and SHM applications.

Speaker



Robin Kim

Associate Professor | Seoul National University

MS 019: High-speed Railroad, Transportation Infrastructure, Lifelines, Structural Health Monitoring, and Management

9:30 AM – 11:30 AM | Location: HUMN 125

Chair(s): Fernando Moreu; Hoon Sohn; Hae Young Noh; Jinwoo Lee; Yiqing Ni

Moderatorss



Fernando Moreu

Associate Professor | University of New Mexico



Hoon Sohn

Professor | KAIST

ID 528: Cost-Effective Structural Health Monitoring of Railroad Bridges via Solar-Powered Wireless Sensors and Cellular Data Transmission

9:30 AM – 9:50 AM

Author(s): Hussein Ali Ahmad, University of New Mexico; Ronan Reza, University of New Mexico; Fernando Moreu, University of New Mexico

In the past, Structural Health Monitoring (SHM) of bridges identified the value of data to prioritize decisions. However, efforts have been restricted to bridges of high performance to owners, and little examples include the use of these sensors to prioritize interventions in bridge networks. We propose using a testbed of railroad bridges to explore collection of simple data that owners can use. This study presents a low-cost, solar-powered wireless accelerometer system for structural health monitoring of railroad bridges. The approach of the design involves cellular (cell tower) communication instead of fixed internet connectivity, which increases its application by stakeholders, as well as its portability in railroads environments. The system records tri-axial acceleration during train passages and transfers the data to a web-based platform for near real-time visualization. Acceleration measurements are processed using numerical integration and filtering to estimate displacement time histories, and peak-to-peak response values are extracted for comparison between train events. The system performance is evaluated through laboratory testing by comparing measurements from the LEWIS 7 sensor with reference systems, including a laser Doppler vibrometer. The results show that the proposed approach can support practical and scalable monitoring of railroad bridges under real train loading conditions. The application of this research is contrasted with a passenger train railroad in New Mexico who is interested in the implementation of this technology in their network. This presentation also includes bridge monitoring discussion with stakeholders and potential use for management of railroad bridge inventory.

Speaker



Hussein Ali Ahmad

Research Assistant at University of New Mexico

ID 699: Observing Shock Waves generated by the High-Speed Rail passing Tunnel through Telecommunication Optical Fiber Cables

9:50 AM – 10:10 AM

Author(s): Jatin Aggarwal, Stanford University; Doyun Hwang, Stanford University; Jingxiao Liu, University of California, Berkeley; Hae Young Noh, Stanford University

The growing deployment of high-speed rail systems subjects tunnel infrastructure to significant dynamic loading. High-speed train entry and exit generate shock waves that induce cyclic stresses in tunnel linings, which can persist beyond train passage and accumulate as fatigue damage or crack propagation. Monitoring these strain responses generated by shock waves is therefore critical for tunnel safety and durability. Conventional pressure and acoustic sensing methods are costly to deploy at scale and lack the spatial resolution required to characterize shock wave effects along extended tunnel sections.

To overcome these limitations, we propose a novel approach that leverages pre-existing telecommunication optical fiber cables, originally installed for station communication, to monitor shock waves in the tunnels. The fibers are transformed into dense arrays of virtual dynamic-strain sensors, providing meter-scale spatial resolution along the tunnel using the principle of Distributed Acoustic Sensing (DAS). As a result, telecom fiber cable captures all the dynamic strains produced by the train passing through the tunnels. However, telecom fiber measurements contain both structural vibrations from train motion and acoustic shock waves.

To tackle this challenge, we apply a frequency–velocity (f – v) filter to isolate the shock-wave component. The telecom fiber data is first transformed from a space-time domain into a frequency (f)-wavenumber(k) domain through the two-dimensional Fourier transform, where the apparent velocity is defined as $v = f/k$. The wavefields generated from the various sources of vibrations travel at their characteristic propagation speeds across the tunnel. As shock waves travel across the air at a speed of 343 m/s, a velocity-domain band-pass mask centered around 343 m/s is applied to retain the shock waves' components and suppress the vibrations from structure and other non-acoustic sources. The proposed approach is validated through field experiments conducted in a 735 m-long high-speed rail tunnel in South Korea. The results demonstrate a 16 dB improvement in signal-to-noise ratio (SNR), increasing from –2.1 dB in the raw measurements to 14 dB after filtering. Our proposed approach demonstrates a cost-effective and scalable method for monitoring shock-wave-induced strains, wave propagation dynamics, and potential indicators of fatigue loading in tunnel linings.

Speaker



Jatin Aggarwal

Mr. | Stanford University

ID 711: Bridge Displacement Field Estimation with Pre-existing Telecommunication Fiber

10:10 AM – 10:30 AM

Author(s): Doyun Hwang, Stanford University; Jatin Aggarwal, Stanford University; Jingxiao Liu, University of California, Berkeley; Biondo Biondi, Stanford University; Hae Young Noh, Stanford University

Monitoring the condition of bridges is critical for enhancing the safety of infrastructure. Displacement in particular is a key measurement for many bridge health monitoring (BHM) tasks, such as load rating and serviceability assessment. Load rating, for example, assesses the performance of a bridge by measuring the displacement or other responses at multiple locations across a bridge subjected to vehicular loading. Thus, many sensing modalities and sensing fusion methods have been developed for displacement estimation. However, such methods often require fixed reference points, sensitive to occlusion, or costly to install and maintain, and thus not scalable for continuously monitoring multiple points along multiple bridges at a city scale.

Our previous works have converted pre-existing, ubiquitous telecommunication fiber optic cables into a dense array of vibration sensors using distributed acoustic sensing (TelecomDAS), utilizing the unscaled dynamic component (1-10 Hz) to identify bridge modal parameters. TelecomDAS measures the phase change in backscatter from laser pulses injected into an optical fiber through an interrogator. When vibration perturbs the fiber, the phase of the backscattered light is changed, which can be converted to strain measurements. One interrogator unit can measure up to 180 km of fiber simultaneously at a meter-scale resolution, enabling a dense, scalable city-wide BHM network.

However, for scaled, accurate displacement, we need the quasi-static (0.1 - 1 Hz) frequency band, as well as recover the amplitude information. To this end, we develop a novel displacement field estimation framework for TelecomDAS. The key challenge is the coupling between the fiber and the bridge that distorts the measurements from TelecomDAS. Telecommunication fiber is often laid inside conduits, which are housed within conduits attached to the bridge via channels, hangers, or clamps. Thus, as the bridge vibration is transferred through these attachments, larger measurement noise is introduced both in the form of mechanical noise from resonances of the attachments, lower strain transfer from loose coupling, and amplitude distortion of the original signal. Given this, directly double integrating strain in the spatial domain will result in the amplification of noise, especially in the low spatial frequency domain where the quasi-static deformation of bridges resides.

To address this, we introduce a physics-informed spatial finite impulse response (FIR) filter to estimate displacement from TelecomDAS. We formulate the FIR filter from minimizing the error between distributed strain and displacement with a regularization term. This suppresses noise in the lower spatial frequency compared to double integration, while satisfying the governing equation between distributed strain and displacement. Thus, a reliable estimation of the quasi-static components of displacement is enabled with TelecomDAS. This framework requires no prior knowledge or assumptions about modal shapes, and only a temporary sensor (e.g., accelerometer) needs to be deployed at calibration time to recover the amplitude information to provide the scaling factor.

Based on this framework, we are able to estimate the displacement field at meter-level density along the bridge using TelecomDAS. Our evaluation results from three in-service bridges achieve sub-millimeter accuracy (average RMSE 0.1 mm) at all points along the bridge.

Speaker



Doyun Hwang

Ph.D. Candidate | Stanford University

ID 858: Distributed Displacement Monitoring of Bridge Structures Using Multi-Modal Sensing with Low-Cost FMCW Radar–Accelerometer Fusion and Existing Fiber-Optic Cable

10:30 AM – 10:50 AM

Author(s): Jigu Lee, Korea Advanced Institute of Science and Technology; Dauri Kim, Korea Advanced Institute of Science and Technology; Haeyoung Noh, Stanford University; Jingxiao Liu, Massachusetts Institute of Technology; Doyun Hwang, Stanford University; Jatin Aggarwal, Stanford University; Sungdong Il, Korea National Railway; Soyeon Kim, Korea National Railway; Hoon Sohn, Korea Advanced Institute of Science and Technology

Bridge infrastructure is fundamental to modern transportation systems, yet comprehensive structural health monitoring (SHM) is often limited by the cost, installation complexity, and scalability of conventional sensing solutions. Reliable estimation of displacement is particularly important for assessing structural behavior, identifying early-stage deterioration, and supporting condition-based maintenance. This study introduces a cost-efficient, multi-modal sensing system that integrates a compact radar–accelerometer sensor for high-resolution local displacement monitoring with distributed fiber-optic measurements obtained from existing telecommunication cables. The proposed sensing unit combines a Frequency Modulated Continuous Wave (FMCW) radar and a tri-axial MEMS accelerometer to continuously measure displacement and acceleration with root-mean-square errors below 0.1 mm. Built entirely from off-the-shelf components—including wireless network microcontroller enabling real-time data updates on dashboards—the device can be produced at a cost below USD 1,000, facilitating large-scale deployment on bridge structures. To ensure robust field performance, a radar target-selection algorithm that leverages both radar and inertial measurements is developed to suppress multi-path interference and phase-wrapping effects commonly encountered in FMCW-based displacement sensing. To extend monitoring coverage beyond discrete locations, pre-existing fiber-optic communication cables are repurposed as distributed strain sensors, enabling continuous measurement of strain and deformation along extended bridge spans without additional cabling or invasive installation. All sensing components, including radar–accelerometer units and fiber-optic interrogators, are time-synchronized using a shared Network Time Protocol (NTP) reference, allowing seamless fusion of local displacements, global strain distributions, and dynamic response data. By integrating precise point-based sensing with wide-area distributed fiber-optic measurements, the proposed system offers a scalable and economical solution for estimating displacement distributions in bridge structures. This multi-modal framework supports early anomaly detection, enhanced serviceability assessment, and data-driven lifecycle management for bridges at every stage of their service life. The system performance is validated through field experiments conducted on highway and high-speed railway bridges, demonstrating reliable displacement estimation under realistic structural and environmental conditions. The results confirm that the proposed multi-modal fusion strategy effectively enhances measurement robustness across varying loading scenarios.

Speaker



Jigu Lee

Korea Advanced Institute of Science and Technology

ID 39: Integrating Tornado-Induced Economic Loss Modeling with AI-Enhanced Classification to Predict Bridge Substructure Vulnerability

10:50 AM – 11:10 AM

Author(s): Mahmoud Bayat, The University of Texas at Arlington

Bridges serve as critical lifelines within transportation networks, yet their vulnerability to increasing extreme weather hazards particularly tornadoes remains understudied and insufficiently represented in current bridge evaluation practices. This work develops a comprehensive framework that integrates tornado-induced economic loss estimation with advanced machine learning methods to predict on-system bridge substructure condition ratings. Using a gravity-based spatial interaction model, this study estimates localized economic impacts from the October 2019 Dallas–Fort Worth tornado event and downscales losses to individual bridges based on structural attributes and census-tract exposure. These loss estimates are merged with National Bridge Inventory data and analyzed using a Random Forest classifier enhanced through Generative Adversarial Networks with Focal Loss (GAN-FL) to correct severe class imbalance. The proposed framework provides a novel, hazard-informed approach to assessing structural resilience, enabling transportation agencies to prioritize monitoring, allocate resources efficiently, and improve post-disaster response strategies.

Speaker



Mahmoud Bayat

Assistant Professor | The University of Texas at Arlington

ID 1031: Multimodal Data Fusion of Distributed Acoustic Sensing (DAS) and Vehicle Sensors for Autonomous Road Infrastructure Monitoring

11:10 AM – 11:30 AM

Author(s): Jinwoo Lee, Korea Advanced Institute of Science & Technology (KAIST); Bomi Kim, Korea Advanced Institute of Science & Technology (KAIST); Yichan An Korea Advanced Institute of Science & Technology (KAIST)

"The large scale and continuous deterioration of road networks, including pavements and bridges, demand a proactive management approach for infrastructure sustainability. Conventional inspection methods often struggle with high operational costs and low frequency when relying solely on specialized equipment and manual labor.

To address these systemic challenges, this study introduces an autonomous monitoring system that leverages Distributed Acoustic Sensing (DAS) integrated with multi-source sensors from non-dedicated vehicles, such as dashcams and accelerometers. In this proposed architecture, pavement data from professional survey vehicles serve as the reference standard for training and validating machine learning algorithms. The system integrates geolocated pavement distress information, detected through vision-based processing, with vertical acceleration profiles and continuous acoustic vibration signals from DAS to predict current infrastructure conditions.

By synchronizing the dynamic data generated by crossing vehicles with the distributed sensing measurements from existing fiber optic cables, we provide a robust and comprehensive approach to monitoring both pavement and bridge health. Beyond the assessment of current states, we introduce a methodology for developing deterioration models using the collected multimodal panel data. These models are designed to improve service life predictions and support optimal asset management strategies aimed at minimizing life-cycle costs. Finally, the paper discusses the future trajectory of automation in road infrastructure management, highlighting advancements in multi-sensor data fusion."

Speaker



Jinwoo Lee

Associate Professor | Korea Advanced Institute of Science & Technology (KAIST)

MS 022: Integration of Physics-based Models with Data for Identification, Monitoring, Estimation, and Uncertainty Quantification

9:30 AM – 11:30 AM | Location: HUMN 1B50

Chair(s): Yang Wang; Hamed Ebrahimi; Babak Moaveni; Haeyoung Noh

Moderators



Yang Wang

Professor | Georgia Institute of Technology



Babak Moaveni

Professor | Tufts University

ID 85: Unscented KalmanNet: Physics-Based, Data-Driven Framework for Nonlinear State Estimation in Structural Systems

9:30 AM – 9:50 AM

Author(s): Minhyeok Ko, The University of Texas at Tyler; Abdollah Shafieezadeh, The Ohio State University

Accurate state estimation under uncertainty remains a longstanding challenge in engineering mechanics such as structural health monitoring, robotics, and autonomous systems. Traditional Kalman Filters (KFs) rely on linear approximations and precise noise models. While variants like the Unscented Kalman Filter (UKF) address nonlinearities through sigma-point transformations, they still depend heavily on accurate system models and known noise characteristics. When system models are uncertain or incomplete, even the UKF may fail to provide reliable estimates.

Recent advancements introduced KalmanNet (KN), a data-driven adaptation of the KF, where the Kalman gain is learned directly from data rather than derived from explicit noise covariance matrices. However, the original KN framework still relies on the linear approximation inherent in the traditional KF formulation. This linearity assumption makes it difficult for KN to handle strongly nonlinear problems, update system parameters, or fully benefit from data-driven training in complex scenarios.

This work presents a preliminary framework called Unscented KalmanNet (UKN), which integrates the unscented transformation of the UKF with the data-driven Kalman gain learning strategy of KN. By incorporating sigma-point-based uncertainty propagation into a learning-based filtering architecture, the proposed approach aims to improve robustness to model uncertainty while maintaining consistency with the underlying system physics.

Preliminary numerical investigations suggest that the UKN framework has the potential to handle strongly nonlinear dynamics and uncertain system parameters more effectively than traditional filtering approaches. Ongoing work focuses on further developing the methodology and evaluating its performance in nonlinear structural dynamics problems relevant to structural health monitoring and system identification. The proposed research is expected to contribute toward data-informed, physics-aware state estimation tools for complex structural systems, with potential applications in digital twin development, adaptive model updating, and early-stage anomaly detection.

Speaker



Minhyeok Ko

Assistant Professor | The University of Texas at Tyler

ID 94: Solution reconstruction with the explicit constraint force method

9:50 AM – 10:10 AM

Author(s): Conor Rowan, University of Colorado Boulder; Kurt Maute, University of Colorado Boulder; Alireza Doostan, University of Colorado Boulder

Using neural networks to discretize solutions of systems governed by ordinary and partial differential equations was first explored more than two decades ago, but has gained real traction more recently under the banner of "physics-informed neural networks" (PINNs). Owing to increased access to computing, automatic differentiation, and powerful open-source machine learning libraries, neural networks have become popular in computational physics, offering extreme flexibility in representing complex functional forms and obviating the need for meshing the computational domain. One use case of PINNs is solution reconstruction, which aims to reconstruct the full-field state of a physical system from sparse measurements. This is done in tandem with the governing equations of the system, known up to some constants, to regularize the regression problem. In practice, however, this may be an ambitious assumption—anything from source terms, to constants, to boundary conditions, to the basic differential structure of the operator may be uncertain. In this work, we treat the missing physics regularizing the regression problem as an "unknown unknown," and develop methods which robustly interpolate noisy measurement data even when the parameterization of the missing physics is inconsistent with the measured system. We show that different formulations of the physics loss lead to different "constraint forces" on the system, and that gaining explicit control of the constraint forces yields better and more customizable reconstructions.

Speaker



Conor Rowan

University of Colorado Boulder

ID 109: Field test on tunnel indirect damage identification from moving train response

10:10 AM – 10:30 AM

Author(s): Qi LI, Tongji University; Xiongyao Xie, Tongji University; Kun Zeng, Tongji University

To explore the potential application of the tunnel damage identification method based on train acceleration, a three-axis accelerometer was installed on a metro train carriage to collect acceleration signals. The original signals are segmented and aligned according to the stations, with data analyzed in terms of station sections. Next, the probability density distribution, fast Fourier transform spectrum, and one-third octave spectrum of the signal are calculated. A time-frequency domain fast analysis software for acceleration data is then developed. By comparing changes in time-frequency domain features, the anomalous section of the tunnel is identified. The results confirm that the tunnel damage identification method based on train acceleration is applicable for real-world metro tunnels.

Speaker



Qi Li

PhD student | Tongji University

ID 116: Active learning with physics-informed neural networks for optimal sensor placement in deep tunneling through transversely isotropic elastic rocks

10:30 AM – 10:50 AM

Author(s): Alec Tristani, Cornell University; Chloé Arson, Cornell University

Accurate characterization of the mechanical properties and in situ stress conditions of deep rock masses remains a critical challenge for the design and monitoring of underground excavations. This study proposes a deep learning framework that simultaneously reconstructs displacement fields and identifies governing parameters of transversely isotropic elastic media surrounding deep circular tunnels while enabling optimal sensor deployment. The approach relies on Physics-Informed Neural Networks (PINNs), which embed equilibrium equations, anisotropic constitutive relations, and boundary conditions directly into the learning process, enabling the solution of partial differential equations and inverse parameter estimation from sparse displacement measurements.

The model is trained using synthetic datasets that emulate typical field measurements obtained from extensometers installed in the rock mass and convergence monitoring at the tunnel wall. Because acquiring in situ data may be costly and often spatially limited, we introduce an active learning strategy to minimize the amount of required observations while maximizing model performance. Epistemic uncertainties are quantified through Monte Carlo dropout, allowing the PINN to identify regions where prediction confidence is lowest. New measurement locations are then sequentially selected in these regions, guiding the optimal placement of additional sensors.

To illustrate the methodology, this active learning-driven PINN framework is applied to a deep circular tunnel excavated in transversely isotropic elastic rock. In particular, we aim to simultaneously reconstruct the displacement field and solve the inverse problem of back-calculating rock properties around the Saint-Martin-la-Porte access gallery, located in Savoie, France. For context, the Saint-Martin-la-Porte access gallery was excavated between 2003 and 2010. During excavation, the rock mass displayed pronounced anisotropic behavior, primarily associated with the Carboniferous formation (also known as the Productive Houillier).

The model successfully reconstructs the full displacement field with relative errors less than 4% using 5 extensometers and accurately estimates key geomechanical parameters, including the Young's moduli, shear modulus, horizontal-to-vertical far-field stress ratio, and the orientation of the planes of isotropy with errors less than 5%. Furthermore, the results demonstrate robust performance even for small, scattered, and noisy datasets, highlighting the potential of the method to significantly reduce monitoring requirements.

The proposed methodology provides a practical and computationally efficient tool for inverse analysis in underground engineering. On an Apple M4 silicon chip, each active learning iteration requires only 2 to 5 minutes, making the approach suitable for near-real-time updating of ground models as new measurements are queried and become available. Ultimately, the framework can support decision-making for optimal monitoring strategies and for adaptive tunnel design and control, enabling engineers to better anticipate and manage ground behavior during excavation.

Speaker



Alec Tristani

Postdoctoral Researcher | Cornell University

ID 150: Physics Enhanced Gradual-Learning for Sensing-Based Simulation of RC Column Force-Displacement Response

10:50 AM – 11:10 AM

Author(s): Mahsa Panahi, University of Illinois Chicago; Amir Iranmanesh, University of Illinois Chicago; Farhad Ansari, University of Illinois Chicago

Bridges play a vital role in transportation infrastructure, and maintaining their performance and reliability is a key engineering challenge, particularly in earthquake-prone regions. Accordingly, accurate estimation of force-displacement responses in reinforced concrete (RC) bridge columns during seismic events is critical for structural health monitoring and post-event decision-making. Sensing-based simulation has emerged as a promising approach by inferring global structural responses from locally measured strain data; however, conventional physics-based methods often suffer from limited accuracy under strong nonlinear behavior and rely heavily on embedded sensors that are typically unavailable in existing structures. To address these challenges, this study proposes a Physics-Enhanced Gradual Learning (PEGL) framework for sensing-based simulation of seismic force-displacement responses in RC columns.

The proposed framework integrates physics-based modeling with data-driven learning while preserving fundamental mechanics. Two model formulations are developed: a residual-based model that learns to correct errors in physics-based predictions, and a direct-prediction model that estimates global force and displacement responses directly from measured strain histories. Both models use Long Short-Term Memory (LSTM) networks to capture the time-dependent characteristics of the seismic response. Continuous strain measurements obtained from fiber Bragg grating (FBG) sensors and computed displacement and force are used as model inputs. The PEGL models are trained using response data from prior seismic events, enabling them to account for cumulative damage, stiffness degradation, and nonlinear hysteretic behavior in subsequent events.

Experimental results demonstrate that the PEGL framework achieves strong agreement with measured force-displacement responses across multiple seismic excitations. Furthermore, the framework maintains high predictive accuracy even when embedded sensors are excluded, relying solely on externally mounted sensors. This capability is particularly important for existing bridges where internal instrumentation is not feasible. These findings highlight the robustness and practicality of the proposed approach for real-time seismic response estimation and structural health monitoring of both newly constructed and existing RC bridge columns.

Speaker



Mahsa Panahi

PhD student in Structural Engineering | University of Illinois Chicago

ID 283: Inverse Finite Element Method-based Deformation Reconstruction of Structures through Distributed Fiber Optic Sensor and Kirchhoff-Love Strip Method

11:10 AM – 11:30 AM

Author(s): Yongfei Li, Purdue University; Xingyu Wang, North Dakota State University; Jiannan Ding, Purdue University; Rongze Hu, Purdue University; Ying Huang, North Dakota State University; Chengcheng Tao, Purdue University

Energy pipelines, storage tanks, and pressure vessels are critical components of energy transportation and storage systems. Their structural safety is directly related to the long-term stable operation of energy infrastructure. During service, these structures are commonly subjected to combined static and dynamic loads. Static loads, including soil overburden pressure, thermal gradients, and self-weight, act continuously throughout the service life. These may induce global bending and creep-type deformations in pipeline structures. Such deformations are challenging to detect promptly because of strong concealment and long-term accumulation. In contrast, dynamic loads arise from third-party construction activities, falling objects, or seismic excitations. They often lead to high-strain responses, resulting in localized dents, buckling, or residual deformations that significantly degrade the load-carrying capacity of the structure.

Distributed fiber optic sensors (DFOS) can provide high-resolution, spatially continuous strain and thermal measurements and therefore exhibit significant advantages in monitoring both static and dynamic structural responses. However, their high system cost and susceptibility to damage under harsh service environments severely limit the feasibility of dense deployment over large-scale structures. The inverse finite element method (iFEM) is a physics-based, data-driven computational framework, which enables the reconstruction of full-field deformation states from a limited number of strain measurements.

In this study, a Kirchhoff-Love theory-based strip computation method (KLSM) is utilized for the efficient reconstruction of deformation fields in pipeline structures. By integrating DFOS strain data, the method is applied to reconstruct deformations under bending, impact, and buckling loading conditions. The accuracy of the KLSM is systematically validated through comparative analyses with finite element simulations, demonstrating good agreement in deformation magnitudes. The results indicate that the proposed KLSM can effectively reconstruct full-field deformation using limited strain measurements. It also provides a promising approach for deformation monitoring and safety feedback mechanisms in energy infrastructure subjected to complex service conditions.

Speaker



Chengcheng Tao

Assistant Professor | Purdue University

MS 026: Modeling of Materials with Interfaces and Scales Using Physics-Based and Machine-Learning Methods

9:30 AM – 11:30 AM | Location: HUMN 150

Chair(s): Xiang Zhang; Pinlei Chen; Kamalendu Ghosh; Balavignesh Vemparala Narayana Murthy; Ravindra Duddu; Soheil Soghrati; Reza Abedi

Moderatorss



Kamalendu Ghosh

Sr. R&D Engineer | Micron Technology



Balavignesh Vemparala

Dr. | Synopsys, Inc.

ID 80: A deep learning U-Net-based surrogate model for the prediction of dynamic fracture propagation in heterogeneous materials

9:30 AM – 9:50 AM

Author(s): Chandu Parimi, BITS Pilani , Hyderabad Campus; Krishnendu Sivadas, BITS Pilani , Hyderabad Campus; Bhavya Karnawat, BITS Pilani , Hyderabad Campus; Hriday Bhuta, BITS Pilani , Hyderabad Campus

Real-time fracture prediction in heterogeneous materials, particularly under dynamic, impulsive, or impact loadings, within a phase field framework, poses significant computational challenges. ML can be used as a practical alternative that serves as a fast-track design tool with reduced complexity and computational time. In this work, we present a methodology for data-driven predictive modeling of dynamic crack propagation in heterogeneous materials, exploring four different deep learning architectures. Although the Graph Neural Network (GNN) is an architecturally appropriate choice, its computational expense is almost equivalent to that of numerical simulations. Resampling the mesh into a regular 512×256 grid using bilinear interpolation enabled the utilization of convolutional architectures, which exhibit superior scalability compared to their graph-based counterparts. Res-UNet is a deep convolutional neural network employed for semantic segmentation tasks. Although this approach showed potential, it experienced severe training instabilities, which resulted in slow convergence despite aggressive learning rate schedules and gradient clipping. The proposed model is built on a deep UNet architecture enhanced by CBAM, which predicts how a crack field propagates from one time step to the next. The model employs an auto-regressive approach, utilizing both current and predicted states at each timestep, and is trained on phase field datasets for dynamic fracture, comprising approximately 200 time steps for each set. The final surrogate model employs a U-Net-based encoder-decoder structure, enhanced with Convolutional Block Attention Modules (CBAM) and Group Normalisation, to enhance representational efficiency and training stability. This design effectively integrates high-level semantic context with fine-grained spatial detail, making it well-suited for image-to-image regression of fracture field evolution. This architecture enables the rapid rollout of dynamic fracture situations across multiple time steps without requiring repeated calls to a full finite element solver. Numerical investigations on heterogeneous material systems demonstrate that the surrogate accurately reflects both the kinematics of crack propagation and the effect of microstructural heterogeneity, with significantly lower computational overhead. The resultant technique serves as a valuable computational tool for rapid design iteration, parametric research, and real-time decision support in dynamic failure analysis in multi-material problems.

Speaker



Chandu Parimi

Associate Professor | BITS Pilani , Hyderabad Campus

ID 91: Data-driven and physics-informed deep learning approaches for solving fracture and diffusion problems in multi-material domains or with multiscale features

9:50 AM – 10:10 AM

Author(s): Yuxiang Gao, Vanderbilt University; Ravindra Duddu, Vanderbilt University; Soheil Kolouri, Vanderbilt University; Abhinav Gupta, Vanderbilt University

The rapid advancement of GPUs led to growing interest in the development of deep learning (DL) models for solving partial differential equations (PDEs), with the goal of accelerating material design and failure prediction. Within the realm of DL, tremendous progress has been made with Multi-Layer Perceptrons (MLPs), Physics-Informed Neural Networks (PINNs) and Convolutional Neural Networks (CNNs), which inspired our research effort. The advanced capabilities of DL can be particularly advantageous for solving fracture and diffusion problems in multi-material domains or with multiscale features, wherein computing the unknown fields and their evolution is crucial but is often computationally costly or time consuming. Particularly, the application of DL for composite fracture and glacier/ice-sheet evolution involving damage transport, remains an area ripe for exploration. This talk will present two DL frameworks: (1) data-driven CNN-based surrogates of the phase field fracture model for inverse design of composites, and (2) physics-informed cell representation for solving elliptic PDEs with multiscale features. First, the development of CNN-based surrogates for predicting damage and stress fields and peak load under uniaxial tension given the 2D microstructure image of a unidirectional fiber-reinforced composite will be discussed (Gao et al., 2023). An inverse design framework that combines this surrogate with a differentiable simulator to optimize the design space parameters of these composite materials will be presented (Gao et al., 2025). Second, an energy loss informed cell-based MLP with an optimized model architecture consisting of multilevel multiresolution grids will be discussed (Gao et al., 2026). Preliminary 2D numerical examples will be presented to highlight improved speed and accuracy in solving PDEs with nonlinear or high-frequency boundary conditions and discuss hyperparameter selection. Concluding remarks will discuss the pros and cons of these approaches and alternative approaches to be considered in future research.

Gao, Y., Berger, M., & Duddu, R. (2023). CNN-Based Surrogate for the Phase Field Damage Model: Generalization across Microstructure Parameters for Composite Materials. *Journal of Engineering Mechanics*, 149(6), 04023025. <https://doi.org/10.1061/JENMDT.EMENG-6936>

Gao, Y., Duddu, R., Kolouri, S., Gupta, A., & Prabhakar, P. (2025). An inverse design framework for optimizing tensile strength of composite materials based on a CNN surrogate for the phase field fracture model. *Composites Part A: Applied Science and Manufacturing*, 192, 108758. <https://doi.org/10.1016/j.compositesa.2025.108758>

Gao, Y., Duddu, R., & Kolouri, S. (2026). Energy loss informed cell-based multilayer perceptron for solving elliptic PDEs with multiscale features. *Computers and Mathematics with Applications*, under review.

Speaker



Ravindra Duddu

Associate Professor | Vanderbilt University

ID 132: Physics-Informed Diffusion Models for Dynamic Fracture Prediction

10:10 AM – 10:30 AM

Author(s): Yi-Chia (Ika) Han, Cornell University; Chloé Arson, Cornell University

Predicting fracture paths in heterogeneous media remains challenging due to the spatial variability of material properties. The phase-field method (PFM), originally developed for interface-evolution problems, has since been adapted to model brittle fracture by representing cracks as diffuse damage zones. Although PFM has been validated across multiple spatial and temporal scales, its computational cost remains high: steep stress gradients require fine spatial resolution, accurate integration demands small time increments, and energy-splitting schemes introduce additional nonlinearities. Given these computational challenges, there is a growing need for fast and reliable surrogate models. Recent work suggests that denoising diffusion probabilistic models (DDPMs) can approximate fracture and stress evolution, but existing studies typically focus on simplified configurations, limited loading scenarios, or short crack trajectories. Furthermore, most implementations lack sequential fracture-field updates and, critically, they rarely embed the underlying physical laws, leading to poor generalization. To address these gaps, this project aims to develop a physics-informed DDPM capable of handling complex geometries, extended crack growth, and fully dynamic loading histories. To generate the training data, fracture simulations are performed using the finite-element phase-field method (PFM-FEM) implemented in RACCOON, which is built on the MOOSE framework. A volumetric-deviatoric energy decomposition is applied to ensure that cracks nucleate and grow only under tensile loading. The resulting displacement fields, damage phase fields, material parameters, and boundary conditions are fed as input channels for the DDPM. During training, the network's predicted displacement and damage fields are evaluated using a composite loss function that incorporates the governing equations, boundary conditions, and data-driven error terms, and the trainable parameters are updated accordingly. After each update, the newly predicted displacement and damage fields replace the previous fields and are fed back into the model to generate the next step in the sequence. This iterative procedure continues until the final simulation time step is reached. The model was evaluated on 12 Mode-I (homogeneous) cases, 12 Mode-II (homogeneous) cases, 9 Mode-I (pre-cracked) cases, and 9 mixed-mode (pre-cracked) cases. The predicted damage phase fields and displacement fields exhibit high accuracy across all scenarios when errors are aggregated over all time steps. These results demonstrate that the proposed physics-informed DDPM is a promising surrogate modeling framework capable of capturing both fracture evolution and deformation fields under complex geometries and loading histories.

Speaker



Yi-Chia Han

PhD student | CORNELL UNIVERSITY

ID 238: Crystal Plasticity Modeling of Ti-6Al-4V Alloy: Explicit Tracking and Mitigation of Micro-Textured Regions for Optimized Thermomechanical Processing

10:30 AM – 10:50 AM

Author(s): Debangshu Paul, University Of Tennessee; Michael Gram, Pratt & Whitney; Adam Pilchak, Pratt & Whitney; Manish Kamal, Pratt & Whitney; Timothy Truster, University Of Tennessee

Ti-6Al-4V (Ti-64) is considered the workhorse alloy in the aerospace industry due to its excellent combination of mechanical properties and corrosion resistance. The occurrence of micro-textured regions (MTRs), in commonly used titanium alloys for aerospace components, may limit fatigue performance via the cold dwell fatigue (CDF) mechanism. CDF leads to accelerated fatigue damage when a material experiences a hold (dwell) at peak stress during cyclical loading. CDF in titanium alloys, including in Ti-64, has demonstrated component and system performance impact in isolated cases for nearly 4 decades.

Existing crystal plasticity frameworks prioritize performance or crack propagation in polycrystal materials, and lack explicit MTR tracking during multi-pass forging. This study performs thermomechanical process (TMP) crystal plasticity simulations with Ti-64 to predict MTR evolution. DAMASK's Fast Fourier Transform (FFT)-based spectral solver was utilized, which enables explicit modeling of texture evolution in polyphase systems through efficient large-scale simulations, resolving the effect of anisotropy on MTR formation. Taylor iso-strain homogenization with a single-crystal grain is employed to calibrate the initial material model, which is subsequently refined using a large representative volume element (RVE) of dual phase microstructure. A detailed microstructural assessment was conducted to establish the microstructure and the RVE employed in the large-deformation simulations. Severe mesh distortion due to heterogeneous plastic deformation in polycrystals is well known. A mesh replacement method was developed to perform simulation of larger plastic strains. By analyzing how variations in strain paths during the forging process affect MTR evolution, this study aims to develop an optimized method for forging with reduced MTR content. This modeling tool has applications for improvements in process and product development and quality control for Titanium alloys, which would be discussed.

Keywords: Taylor Homogenization, Adaptive remeshing, Mesh replacement, Ti-64, Titanium alloy, Thermomechanical process, Hot forging simulation, Micro-textured region, MTR.

Acknowledgements: We gratefully acknowledge the financial support provided by RTX Corporation, Pratt & Whitney Division, and the Air Force Research Laboratory (AFRL) under contract #FA865023-C-5311. Additionally, we extend our appreciation to the RTX team members for providing background information and expert guidance on the project. Their insights were instrumental in ensuring the reliability of the data used in this study.

Speaker



Debangshu Paul

Graduate Research Assistant | University of Tennessee

ID 323: Investigation of Surface Roughness and Void Effects on the Fracture Behavior of Adhesively Bonded Joints

10:50 AM – 11:10 AM

Author(s): Kinan Bezem, University of Tennessee; Stephanie TerMaath, University of Tennessee

Joining dissimilar materials to create layered structures enables lightweight tailored designs for demanding performance requirements. Adhesive joining is a key enabler because it provides load transfer without the weight and stress concentrations associated with traditional mechanical fastening. In these systems structural integrity is governed by bondline behavior which is strongly influenced by microstructural variability introduced during processing. Surface preparation produces interfacial roughness and can promote defect populations such as voids within or near the bondline both of which can affect damage initiation localization and the evolution toward catastrophic fracture. Understanding how these microstructural features translate into fracture response and into effective traction separation behavior under load is essential for reliable design.

This work presents a peridynamics based framework for linking statistically described bondline microstructure to measured fracture behavior with emphasis on void driven effects quantified through specimen level testing. Probabilistic descriptions of microstructural features are used to generate ensembles of peridynamic models enabling controlled studies of void content void size distributions and spatial arrangement while naturally capturing progressive damage and crack growth. The approach is demonstrated using adhesive dogbone tensile tests with statistically generated void distributions providing global response metrics such as stiffness peak stress strain to failure and variability across realizations that explain fracture sensitivity to void neighborhoods. Within the broader multiscale project these peridynamics results are positioned as a route to inform higher scale models by supplying physically grounded failure descriptors and uncertainty bounds that can be translated into reduced order constitutive representations for structural simulation.

Speaker



Kinan Bezem

Post Doctoral Researcher | University of Tennessee

ID 347: Multiscale Image-Based Inference of Concrete Mechanical Properties Using Deep Learning

11:10 AM – 11:30 AM

Author(s): Naiara R. Tonin, University of Colorado Boulder; Mija Hubler, University of Colorado Boulder

Construction remains among the least automated fields in engineering, despite the growing availability of data and sensing technologies. Current methods for assessing concrete mechanical performance are time-consuming, costly, and strongly dependent on expert judgment, limiting their applicability for routine or large-scale evaluation. An image-based framework is developed to estimate concrete mechanical properties through automated analysis of surface photographs. Surface texture is encoded using a Synthetic Micropixel (SMP) representation that links optical features to indentation-derived stiffness and hardness at the pixel scale. These physically grounded descriptors are used to train a convolutional neural network (CNN) that maps surface morphology to macroscale mechanical response while preserving spatial correspondence and interpretability. The method requires minimal surface preparation and no fixed specimen geometry, enabling analysis of irregular cuts, cores, or post-failure fragments. The framework supports image-based inference of stress–strain response, stiffness contrast, brittleness, and creep-related tendencies, demonstrating the potential of automated visual analysis as a scalable tool for concrete assessment.

Speaker



Naiara Tonin

PhD in Structural Engineering & Mechanical Engineering | University of Colorado Boulder

MS 029: Leveraging Artificial Intelligence for the Computational Modeling of Quasi-Brittle Infrastructure Materials

9:30 AM – 11:30 AM | Location: HUMN 1B90

Chair(s): Gianluca Cusatis; Gilles Pijaudier-Cabot; M. Z. Naser; Mohammed Alnaggar; Giovanni Di Luzio

Moderators



Gianluca Cusatis

Dr | Northwestern University

ID 38: Data-Driven Uncertainty Quantification of Concrete Mesoscale Behavior Using Multiscale Observations

9:30 AM – 9:50 AM

Author(s): Baixi Chen, University of Pittsburgh; Alessandro Fascetti, University of Pittsburgh

The macroscopic failure behavior of concrete exhibits pronounced variability originating from the stochastic nature of its constituent materials at the mesoscale. However, identifying mesoscale material parameters remains challenging, making uncertainty quantification at this scale a persistent problem. This work introduces a data-driven multiscale inverse inference framework that integrates both mesoscale and macroscale observations to quantify stochastic mesoscale behavior. First, a stochastic data-driven model is developed using a hybrid Proper Orthogonal Decomposition–Gaussian Process Regression (POD–GPR) approach trained on the simulation results of the mesoscale Lattice Discrete Particle Model (LDPM). Building on this surrogate, a multiscale Bayesian inverse inference method is formulated to estimate the probabilistic distributions of mesoscale features. Applied to experimental data, the proposed framework accurately quantified uncertainty in mesoscale features, reproduces stochastic macroscopic responses, and demonstrates clear advantages over traditional single-scale Bayesian inference. Furthermore, SHapley Additive exPlanations (SHAP) are incorporated to interpret how mesoscale uncertainties propagate to the macroscopic scale, providing insight for improving the LDPM approach and guiding mesoscale-level material optimization for enhanced structural reliability.

Speaker



Baixi Chen

Dr. | University of Central Florida

ID 278: Integrated Finite Element Neural Networks (I-FENN) for accelerating the solution of coupled problems

9:50 AM – 10:10 AM

Author(s): Mostafa Mobasher, New York University Abu Dhabi; Panos Pantidis, New York University Abu Dhabi; Diab Abueidda, New York University Abu Dhabi; Habiba Eldababy, New York University Abu Dhabi; Fouad Amin, New York University Abu Dhabi

Many engineering problems involve strongly coupled multiphysics and nonlinear phenomena whose numerical solution becomes prohibitively expensive at scale. To address this challenge, the Integrated Finite Element Neural Network (I-FENN) framework has been developed as a hybrid modeling paradigm that synergistically combines the robustness of the Finite Element Method (FEM) with the efficiency and expressiveness of neural networks. In I-FENN, a pre-trained neural network is embedded within a FEM solver in a staggered formulation, where FEM resolves the mechanical equilibrium while the neural network predicts the coupled or auxiliary physics, thereby reducing the number of finite-element unknowns and significantly lowering the computational cost.

The I-FENN framework has been extended to a broad class of multiphysics problems, including thermoelasticity and poroelasticity, as well as nonlinear mechanics applications such as nonlocal continuum damage and phase-field fracture. In these settings, neural networks are employed as surrogate PDE solvers to approximate additional physics beyond elasticity—such as heat conduction, pore-pressure diffusion, or phase-field evolution—and their outputs are incorporated into the FEM solver as material point variables. This strategy preserves the favorable numerical properties of FEM, including stability and accuracy, while leveraging fast network inference to accelerate coupled simulations.

Recent developments within I-FENN introduce advanced network architectures with enhanced generalization capabilities, including deep operator networks for handling diverse boundary conditions and loading scenarios, as well as physics-informed convolutional networks for fracture modeling. In particular, learning the spatial coupling between strain energy density and auxiliary fields enables accurate prediction of complex phenomena without explicit temporal modeling, allowing a single minimally trained network to generalize across unseen geometries, meshes, loading paths, and interaction scenarios. Benchmark studies across multiple coupled problems demonstrate that I-FENN achieves substantial computational savings that scale with problem complexity while maintaining high accuracy in critical regions of the domain.

Overall, these results highlight the potential of I-FENN as a general, physics-consistent, and highly efficient hybrid solver for large-scale multiphysics and nonlinear engineering problems, offering a new paradigm for integrating machine learning within established numerical methods.

1-Pantidis, P., Svolos, L., Abueidda, D., & Mobasher, M. E. (2026). Integrated Finite Element Neural Network (IFENN) for phase-field fracture with minimal input and generalized geometry-load handling. *Computer Methods in Applied Mechanics and Engineering*, 448, 118485.

2-Amin, F. M., Abueidda, D. W., Pantidis, P., & Mobasher, M. E. (2026). I-FENN with DeepONets: accelerating simulations in coupled multiphysics problems. *Computer Methods in Applied Mechanics and Engineering*, 451, 118645.

Speaker



Mostafa Mobasher

Assistant Professor | New York University Abu Dhabi

ID 318: Concrete Modeling in the Era of Machine Learning

10:10 AM – 10:30 AM

Author(s): Gianluca Cusatis, Northwestern University

This presentation offers a reflection on the status of computational modeling of concrete in a new era of advanced computational technologies readily available to researchers. It will first review the successes (and the drawbacks) of the last 25 years of high-fidelity computational modeling for concrete at various length scales and it will propose a vision for the future developments of the field. The presentation will discuss various computational approaches, but it will primarily highlight the benefits and superior modeling capabilities of discrete models, such as the Lattice Discrete Particle Model (LDPM). LDPM simulates accurately heterogeneous materials by directly linking the discreteness of the formulation with material heterogeneity at various length scales. In the last few decades, LDPM has been adopted successfully to simulate quasi-brittle failure and fracture under multiaxial loading conditions and dynamic loadings; to capture the multiphysical behavior of concrete and other quasibrittle materials under varying temperature and relative humidity; and to predict the response of reinforced concrete structural elements.

The second part of the presentation will discuss recent work coupling LDPM with Machine Learning (ML) techniques for several applications, including fast parameter identification, fragmentation characterization, and macroscopic constitutive modeling from fine-scale computational data. For parameter identification, the presentation will show results obtained by exploiting ML to obtain metamodels for typical laboratory tests for concrete, namely unconfined compression test, hydrostatic test, and three-point bending test. By using these ML metamodels the computational cost for a typical LDPM parameter optimization task is reduced by several orders of magnitude without sacrificing accuracy in the optimized parameters. The second ML study focuses on predicting and quantifying fragmentation phenomena under high impulsive dynamic loading via an innovative unsupervised learning clustering technique to identify and characterize mass and velocity of fragments. Results show excellent agreement with some available experimental data. A third ML application that will be discussed is relevant to the formulation of a macroscopic tensorial constitutive equation via the ML interpolation of a large database of homogenized LDPM response obtained with randomly generated strain histories featuring complex loading-unloading-reloading histories. The study highlights the limitations of methods that have been proposed in the literature but that have been only applied to relatively simple material behavior such as elasticity and classical plasticity.

Speaker



Gianluca Cusatis

Dr | Northwestern University

ID 643: Data-Driven Hyper-Reduction of the Lattice Discrete Particle Model for Fracture Simulation

10:30 AM – 10:50 AM

Author(s): Nima Noorollahi, University of Pittsburgh; John Brigham, University of Pittsburgh; Alessandro Fascetti, University of Central Florida

The Lattice Discrete Particle Model (LDPM) provides a detailed mesoscale description of fracture and strain localization in quasi-brittle materials, enabling explicit representation of crack initiation, propagation, and interaction across multiple length scales. Despite its strong physical fidelity, the computational cost of LDPM remains prohibitive for large-scale simulations, parametric studies, and analyses involving complex geometries, boundary conditions, or dynamic loading scenarios commonly encountered in infrastructure applications.

Previous work reduced the computational cost associated with LDPM displacement calculations by lowering the number of degrees of freedom using Proper Orthogonal Decomposition (POD). While this approach significantly reduced the kinematic dimensionality of the problem, the dominant computational expense persisted due to the full-order evaluation of nonlinear internal forces and the evolution of associated internal variables governing fracture and inelastic behavior. As a result, further efficiency gains require targeted reduction of force computations while preserving accuracy in regions of strain localization and damage evolution.

This work advances LDPM model reduction by introducing data-driven hyper-reduction strategies that build upon POD-based displacement reduction and employ Energy-Conserving Sampling and Weighting (ECSW) to approximate nonlinear internal forces using only a small, strategically selected subset of lattice interactions. The sampling strategy prioritizes lattice interactions that contribute most significantly to internal force development and energy dissipation, which are critical for accurately capturing fracture evolution. In addition, the potential application of a QR-based Discrete Empirical Interpolation Method (QR-DEIM) is investigated as an alternative strategy for internal force approximation based on snapshot data.

The resulting formulations are designed for incremental, on-the-fly integration within an explicit dynamic LDPM solver, allowing the reduced model to naturally adapt as damage, strain localization, and fracture patterns evolve during the analysis. The proposed approach is assessed across multiple loading configurations and boundary conditions, demonstrating accurate reproduction of displacement fields, crack initiation patterns, and post-peak fracture pathways while achieving substantial computational savings. A systematic investigation further reveals how small discrepancies in displacement fields can lead to amplified internal force errors in localized regions, highlighting the sensitivity of force responses to local kinematic accuracy.

Overall, this study establishes a scalable and data-driven pathway toward efficient LDPM simulations for fracture-dominated problems in quasi-brittle infrastructure materials, addressing key challenges related to computational performance, accuracy, and dynamic response.

Speaker



Nima Noorollahi

PhD Candidate | University of Pittsburgh

ID 813: On the calibration and formulation of a damage-based model for structural failure on the basis of meso-structural simulations

10:50 AM – 11:10 AM

Author(s): Gilles Pijaudier-Cabot, Université de Pau et des Pays de l'Adour (UPPA); Jad Mounayer, École nationale supérieure d'Arts et Métiers | ENSAM; Sebastian Rodriguez, École nationale supérieure d'Arts et Métiers | ENSAM; Francisco Chiniesta, École nationale supérieure d'Arts et Métiers | ENSAM; Cino Viggiani, Grenoble University; Filippo Masi, French Institute for Research in Computer Science and Automation; Julien Khoury, Université de Pau et des Pays de l'Adour (UPPA); Gianluca Cusatis, Northwestern University

Devising proper models that describe failure due to strain softening and damage localization in quasi-brittle materials is still an open issue related (i) to the physical argument that underlies the enrichment that is needed to cope with bifurcation and instability due to strain localization, and (ii) how to calibrate the new model parameters that enter such enrichments. In this presentation, we start from the calibration issue in the context of finding a macroscale damage model that is equivalent to a state-of-the-art mesoscale model: the lattice discrete particle model (LDPM).

When gradient or integral damage models are considered, the current is to fit structural responses of specimens of various sizes. Structural size effect triggers the influence of the internal length involved in these models and allows its calibration. Here we show that an alternative way is to calibrate the model using full-field (strains and stresses) data instead of pointwise displacement and load histories. As a result, there is no need to consider size effect because correlation involved in the failure process is embedded in the full-field data.

The above calibration procedure is based upon the complete knowledge of the constitutive equations whose mathematical expression is known in advance. This step can be alleviated by considering the data-driven approach introduced by Ortiz and co-workers. Instead of being described by equations, the evolution of damage is defined as a set of data points, not by equations. In the present context, this dataset is directly generated from LDPM calculations and used to run computations with a macroscale damage model. Unfortunately, instead of having complex mathematical expressions for the evolution of damage, it is the dataset that becomes complex. More precisely, it should incorporate the correlation due to nonlocality, meaning that it should encompass all possible size or shape effects. This goal can hardly be reached, and the question goes back to the physical significance of nonlocal, integral or gradient, variables that arise when going from meso-scale local models such as LDPM to macroscale damage models with an internal length.

Such a significance is considered here with the help of machine learning. Here, data are those obtained by mesoscale model (LDPM) computations and they are compared to a macroscale model. First, we show that when considering computations on dog-bone experiments of various sizes, the equivalent macroscale model should encompass one added variable interpreted as the fracture energy. Then, we demonstrate that useful pieces of information can be extracted by considering the residual between the mesoscale and macroscale full field responses. Independent variables that control the residual, i.e., the error between the mesoscale and macroscale models, can be extracted and may inform more accurate macroscale constitutive models.

Speaker



Gianluca Cusatis

Dr | Northwestern University

ID 640: Optimizing Concrete Mixtures with AI: From Open-Source Models to Data-Center Deployment

11:10 AM – 11:30 AM

Author(s): Nishant Garg, University of Illinois Urbana-Champaign

Modern concrete must meet growing demands for mechanical performance, workability, durability, and sustainability, making mix design increasingly complex. While recent AI/ML approaches show promise for predicting compressive strength and optimizing mixes, most rely on proprietary datasets and closed-source models. We introduce an open-source AI model trained on a new open-access dataset comprising over 500 strength measurements (1–15 ksi) from 123 mortar (69) and concrete (54) mixes tested at five ages (1, 3, 5, 14, and 28 days). The dataset was generated at the University of Illinois using materials imported from a Minnesota data center site. Using Gaussian Process Regression with Bayesian Optimization, the model accurately forecast strength development while quantifying uncertainty ($R^2 = 0.95$, RMSE = 670 psi). The model further enabled optimized, lower- CO_2 , higher-performance mix designs deployed in floor slabs of a data center opening in 2026.

Speaker



Nishant Garg

Associate Professor | University of Illinois Urbana-Champaign

MS 041: Cementitious Materials: Experiments and Modeling Across the Scales

9:30 AM – 11:30 AM | Location: CLUB 4-5

Chair(s): Bernhard Pichler; Gilles Pijaudier-Cabot; Günther Meschke; Christian Hellmich; Franz Josef Ulm

Moderators



Christian Hellmich

Prof. | TU Wien/IMWS

ID 510: Bridging the scales of microstructural and structural concrete fatigue degradation using a thermodynamically based discrete modeling framework

9:30 AM – 9:50 AM

Author(s): Mario Aguilar, Center for Structural Concrete Physics, RWTH Aachen University; Miroslav Vořechovský, Institute of Structural Mechanics, Brno University of Technology; Rostislav Chudoba, Center for Structural Concrete Physics, RWTH Aachen University

Predicting the fatigue life of concrete structures requires models that not only reproduce structural-scale response, but also embed the influence of microstructural features and damage mechanisms. This contribution presents a thermodynamically based multi-scale modeling framework in which material parameters are calibrated at the mesoscale and the subsequent validation is performed at the structural scale through prediction of the compressive fatigue response of a prestressed concrete beam. At the mesoscale, the model explicitly represents the heterogeneous concrete microstructure through a discrete particle lattice, while the inter-aggregate behavior is governed by constitutive laws derived within a generalized thermodynamic framework designed to accommodate temperature-, rate-, moisture- and hydration-level-dependent behaviors that are critical for concrete fatigue.

Mesoscale calibration is carried out using material properties of the concrete mix used in the beams, including elastic modulus, strength, the slope of the Sparks–Menzies relation and the S–N curve, and stiffness degradation characteristics. Once calibrated, the same set of parameters is employed to predict the fatigue behavior of concrete structures.

The predictive capability of the multiscale framework is demonstrated through numerical analysis of a prestressed beam bending test specifically designed to investigate structural compressive fatigue, which is highly relevant for components of high-speed railway bridges and hybrid wind power plants. The simulations reproduce key structural-scale fatigue phenomena, including S–N curves, the Sparks–Menzies relation, progressive damage localization in the compressive zone, and internal stress redistribution as microcracking and crushing evolve. A direct comparison between material- and structural-scale S–N curves and Sparks–Menzies relations highlights both their differences and the extent to which fatigue characteristics can be transferred across scales.

A key finding of this study is that the energy dissipated by damage up to failure remains nearly constant across different loading levels and fatigue lifetimes, scaling with the size of the fatigue process zone. This indicates that the material exhibits a characteristic energy absorption capacity per unit volume that is exhausted during fatigue degradation, independent of the applied fatigue loading sequence. The proposed multiscale thermodynamic lattice framework demonstrates how microstructure-informed and calibrated models can reliably bridge material- and structural-scale fatigue behavior, paving the way toward more efficient and reliable design of concrete infrastructure subjected to compressive fatigue.

Speaker



Mario Aguilar Rueda

Research Associate | Center for Structural Concrete Physics, RWTH Aachen University

ID 576: Numerical analysis and evaluation of fiber pullout behavior of steel fibers embedded in ultra-high-performance concrete

9:50 AM – 10:10 AM

Author(s): Seda Mursel, University of Texas at Austin; Berkin Dortdivanlioglu, University of Texas at Austin; Anca Ferche, University of Texas at Austin

Due to its outstanding mechanical properties and durability, ultra-high-performance fiber-reinforced concrete (UHPFRC) has attracted significant attention as a composite material with strong potential to influence the future of civil infrastructure. Despite several successful applications, the broader structural use of UHPFRC remains limited, primarily due to an incomplete understanding of its mechanical behavior and the micromechanical mechanisms governing fiber–matrix interaction. Discrete modeling of individual fibers in cement-based materials has demonstrated clear advantages, as it enables direct simulation of fiber debonding, pullout, and post-cracking composite response. This study presents a mesoscale finite element framework developed at the single-fiber length scale to predict the quasi-static pullout behavior of steel fibers embedded in UHPFRC. The proposed model explicitly represents the UHPC matrix, steel fiber inclusions, and their imperfect interfaces. A three-dimensional finite element formulation incorporating zero-thickness cohesive interface elements is employed to capture the pullout response with different geometries. The framework accommodates a wide range of fiber configurations and enables systematic parametric studies. The primary variables investigated include fiber geometry, inclination angle, cross-sectional shape, embedded length, and fiber length-to-diameter ratio. The numerical model consists of a linear elastic UHPC matrix and elastoplastic steel fibers, coupled through a cohesive traction–separation law to represent interfacial debonding and slip. Experimental single-fiber pullout data are used to calibrate and validate the model, demonstrating good agreement in terms of peak pullout load and post-peak response. While single-fiber analyses provide valuable insight into geometric and interfacial effects, practical UHPFRC applications typically involve multiple fibers embedded in close proximity, where fiber content and spatial arrangement play a critical role in tensile performance. To address this, the study is extended to investigate multi-fiber pullout behavior under more realistic conditions. Additional simulations are conducted with multiple fibers embedded within the same matrix domain, accounting for different fiber volume fractions and corresponding inter-fiber spacings. Bundle-type configurations with zero spacing between fibers are also examined to evaluate collective or group effects. The proposed mesoscale approach enhances the understanding of both single- and multi-fiber pullout mechanisms in UHPFRC and provides a robust numerical tool for linking fiber-scale behavior to macroscopic structural performance. The findings offer valuable insights for optimizing fiber content, geometry, and distribution in UHPFRC design and support the development of more reliable multiscale modeling strategies for structural applications.

Speaker



Seda Mursel

Graduate Research Assistant | The University of Texas At Austin

ID 606: Framework for Mix Design Relations of Low-embedded Carbon Using Local Materials

10:10 AM – 10:30 AM

Author(s): Bola Odunaro, University of Colorado Boulder; Mija Hubler, University of Colorado Boulder; Jeong-Hoon Song, University of Colorado Boulder

Title: Framework for Mix Design Relations of Low-embedded Carbon Using Local Materials

Authors:

Dr. Hubler, Mija, University of Colorado Boulder, USA

Dr. Jeong-Hoon Song, University of Colorado Boulder, USA

Odunaro, Bola Pius, University of Colorado Boulder, USA

Recently, many low-embedded-carbon construction materials have emerged to reduce carbon emissions from concrete and the construction sector's overall carbon footprint. However, for these new cement types, which are widely supported globally, low-carbon cement must meet the specified compressive strengths required for structural design when combined with locally available aggregates. Variability in local aggregate properties, combined with challenges in mixing and placing concrete using these innovative low-carbon technologies, has limited the implementation of these materials in construction. This study develops a performance-based framework that links low-carbon binders and local aggregate characteristics to the mix-design adjustments required to achieve target performance across regions. Six/seven binder compositions representing conventional and low-carbon systems (including OPC, Type IL, slag, and fly ash/slag–Type IL blends at multiple replacement levels) were evaluated with four aggregate sources (granite, Colorado Rose, river rock, and recycled aggregate) and aggregate volume fractions of 40–60%. A comprehensive experimental study was conducted, including 28-day concrete compressive-strength testing, mortar compressive/flexural/splitting tensile testing, mini-slump assessment, and drying-shrinkage measurements to quantify both mechanical capacity and cracking risk relevant to concrete performance. Results indicate that OPC, Type IL, and fly ash–Type IL blends provide the most consistent attainment of target strength ranges across aggregate types and volume fractions. In contrast, slag exhibited poor 28-day strength development and elevated shrinkage, consistent with increased microcracking and ITZ degradation under the tested conditions. Aggregate effects were significant: rough/angular aggregates generally improved strength and reduced variability, while recycled aggregate increased scatter, consistent with absorption and porosity effects. The proposed framework provides practical guidance for tailoring low-carbon concrete mix designs to local materials while balancing concrete strength.

Speaker



Bola Odunaro

University of Colorado Boulder

ID 637: From Days to Minutes

10:30 AM – 10:50 AM

Author(s): Nishant Garg, University of Illinois Urbana-Champaign

Traditional testing for cement-based materials has been historically time-intensive, ranging from days to weeks to sometimes even several months. Recent advances in instrumentation, low-cost sensors, and AI can accelerate some of these traditional tests. In this talk, I will outline our recent efforts to speed up testing from the timescale of days to minutes. Specifically, I will talk about three areas. The first area is that of size and shape analysis of a variety of concrete ingredients and pinpointing their impact on macro-scale performance. Examples range from using Raman Imaging for quantification of cement clinker phases to low-cost optical imaging of fine aggregates. The second area is of SCM reactivity testing, where we've introduced a new UR2 test that can predict the 7d R3 and 28d SAI test results in a matter of 5 minutes. Finally, the third area is that of durability testing, where we've introduced newer computer vision-based methods that can predict sorptivity in a matter of few seconds. Overall, with these approaches, we aim to strive towards a future where rapid testing can lead to rapid deployment of novel materials.

Speaker



Nishant Garg

Associate Professor | University of Illinois Urbana-Champaign

ID 962: Modeling Moisture Capacity of Cementitious Materials Incorporating Nano-Silica Using BET Test Analysis

10:50 AM – 11:10 AM

Author(s): Mohammed Z. Zainy, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder; Hailey C. Loehde-Woolard, Department of Chemical and Biological Engineering, University of Colorado Boulder; Alan W. Weimer, Department of Chemical and Biological Engineering, University of Colorado Boulder; Mija H. Hubler, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder; Jeong-Hoon Song, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder; Yunping Xi, Department of Civil, Environmental, and Architectural Engineering, University of Colorado Boulder

The primary goal of this study is to develop a moisture capacity model for cementitious materials with nano silica using the Brunauer-Emmett-Teller (BET) method. The main objective was to predict the moisture capacity of cement pastes containing three different nano silica dosages as a cement replacement and two different sizes. The goal was achieved by using a 3 parameters BET model and establishing a relationship between the monolayer capacity (V_m), and the number of adsorbed layers at saturation (n) with the nano silica size and dosage percentage. Cement paste samples were prepared with water cement ratio of 0.44. The dosage percentages included in this test are 0%, 0.5%, 1.0% and 1.5%. Two different sizes were used: 7nm and 22nm. Thus, a total of seven different mixes were developed. Samples were cured for 28 days in a room temperature reservoir. After that, BET tests were performed following a standard drying procedure. Test results were delivered using nitrogen adsorption which needed to be converted to reflect water adsorption mechanism. Results from the test were compared to the control samples (without nano silica) to establish the models for the monolayer capacity and the number of adsorbed layers at saturation function. Previously developed models for V_m and n of cementitious materials without nano silica were used as base models which were modified to include the effects of nano silica sizes and dosages. The proposed models show a good prediction of the moisture capacity of cement paste with nano silica compared to the experimental results. The findings of this study will offer a significant development in optimizing the use of nano silica in cement industry as well as improving the prediction models of transport properties of cementitious materials with the addition of nano silica.

Speaker



Mohammed Zainy

University of Colorado Boulder

ID 734: Colloidal nanosilica promotes high-density calcium-silicate-hydrates in fine recycled concrete aggregate mortar

11:10 AM – 11:30 AM

Author(s): Ange Therese Akono, North Carolina State University; Nathaniel Buettner, Northwestern University

The use of recycled concrete aggregates for new concrete production is an important avenue to increase the sustainability of concrete. While numerous studies have demonstrated the benefit of nanosilica on recycled aggregate concrete, a connection between the enhanced properties and the properties of the calcium-silicate-hydrates is unproven. Thus, we investigate how nanosilica modifies the distribution of calcium-silicate-hydrates in fine recycled concrete aggregate mortar. Using an interdisciplinary approach of nanomechanical testing, data science, and advanced chemical, microstructural and pore structure characterization, we find that 12 wt.% nanosilica results in a 30.8% increase in the combined relative amount of high-density and ultra-high-density C-S-H, 16.7% reduction in C-S-H gel porosity, 24.4% reduction in total porosity, and 3.9% increase in fracture toughness.

Speaker



Ange Therese Akono

Associate Professor | North Carolina State University

MS 038: Mechanics and Modeling of Durable and Resilient Pavements

9:30 AM – 11:30 AM | Location: CASE E230

Chair(s): Jamilla Teixeira; Shane Underwood; Nam Tran; Ramez Hajj

Moderators



Saqib Gulzar

Assistant Professor | Colorado State University Pueblo

ID 57: Response Characteristics of Asphalt Pavements under Moving Truck Loads

9:30 AM – 9:50 AM

Author(s): Zhaojie Sun, University of Cambridge; Ze Zhou Wang, University of Cambridge; Xiang Wang, University of Cambridge; Linjun Lu, University of Cambridge; Lavindra de Silva, University of Cambridge; Ioannis Brilakis, University of Cambridge

Road infrastructure needs regular inspections to check whether its service performance still meets requirements. A promising approach to efficiently evaluate the structural condition of pavements is the Traffic Speed Deflectometer (TSD) test, which can measure the response (slope of vertical deflections) of pavement surfaces caused by a moving truck load at normal driving speeds. The accurate interpretation of TSD measurements needs a clear understanding of the behaviors of asphalt pavements in this test. To achieve this goal, a theoretical model of TSD tests called PaveMove was developed by using the Spectral Element Method (SEM). This model can properly simulate layered pavement structures, moving surface loads, viscous and hysteretic damping, all loading axles, and different interface bonding conditions. Furthermore, this SEM-based model is computationally efficient because each element can simulate the behaviors of a whole layer or half-space. The developed PaveMove model was used to investigate the influence of different factors on pavement response caused by moving truck loads, such as pavement temperature, operating speed, load superposition, and interface condition. Based on the response characteristics of asphalt pavements in TSD tests, the right way to convert slopes to deflections was investigated because deflections are commoner to be used for structural evaluation of pavements. The results show that higher pavement temperatures lead to significantly larger peak values of vertical deflection and deflection slope, while higher TSD operating speeds result in slightly smaller peak values of deflection and slope. Hence, the speed effect is less significant than the temperature effect, which can be quantitatively described as an increase in operating speed of 8 km/h is roughly equivalent to a decrease in pavement temperature of 1 °C. Furthermore, the load spatial superposition effect is significant in most cases, so all TSD loading axles should be considered to accurately simulate TSD tests. Moreover, poorer interface conditions lead to obviously larger peak values of deflection and slope, indicating the necessity to carefully consider interface conditions when analyzing TSD measurements. In addition, according to the response characteristics of asphalt pavements in TSD tests, an approach called Flexible-Reference Integral Method (FRIM) was proposed to reliably convert slopes to deflections. The FRIM can produce accurate deflection curves regardless of reference points. These findings promote the development of improved analysis techniques of TSD measurements. Ultimately, this study contributes to more effective pavement evaluation and management at the network level.

Speaker



Zhaojie Sun

Postdoc Researcher | University of Cambridge

ID 185: Probabilistic Modeling of Spacings of Thermal Cracks in Asphalt Pavements

9:50 AM – 10:10 AM

Author(s): Jia-Liang Le, University of Minnesota; Yangyi Liu, University of Minnesota; Mihai Marasteanu, University of Minnesota

In this study, a stochastic framework for predicting thermally induced tensile cracking in asphalt pavements is developed. Spatial variability in the stiffness of both the asphalt layer and the base course is represented using homogeneous random fields. Employing a strength-based failure criterion, the model predicts the probability distribution of crack spacing in pavements subjected to a prescribed temperature drop. Parametric studies are performed to investigate the influence of the statistical characteristics of the asphalt material and base course on thermal crack spacing. The framework is further used to determine the maximum allowable pavement length corresponding to a specified target probability of cracking. In parallel, an analytical model is developed to estimate the probability of cracking for a given pavement configuration. The resulting analytical solution establishes an explicit relationship between the maximum allowable pavement length and the material tensile strength for a prescribed probability of cracking, and shows excellent agreement with numerical simulations. This relationship provides a theoretical foundation for the reliability-based design of saw-and-seal operations in asphalt pavements.

Speaker



Yangyi Liu

Graduate Student | University of Minnesota, Twin Cities

ID 560: Comparison of Finite Difference and Finite Element Methods for Modeling Chloride Diffusion in Concrete

10:10 AM – 10:30 AM

Author(s): Ramin Pahnabi, Brigham Young University; Kendrick Shepherd, Brigham Young University; Spencer Guthrie, Brigham Young University

Chloride-induced corrosion of steel reinforcement in concrete can result in structural degradation, safety issues, reduced lifespan, and financial losses. A proper understanding of chloride ion ingress into concrete and effective mitigation of its effects is crucial for preventing corrosion and premature failure of reinforced concrete structures. Previous National Institute of Standards and Technology (NIST) software employed the Finite Difference Method (FDM) to evaluate chloride diffusion in unreinforced concrete; however, this approach is not readily extensible to modeling reinforced concrete conditions with complex geometries. The purpose of this study is to develop Finite Element Method (FEM) software that can exactly reproduce the time-tested NIST FDM results and then be extended to handle more general and complex geometries, such as concrete containing reinforcing steel.

Speaker



Ramin Pahnabi

Mr. | Brigham Young University

ID 767: Rutting performance prediction of flexible airfield pavements using nonlinear mechanistic models

10:30 AM – 10:50 AM

Author(s): Masoud Darabi, University of Kansas

The rutting performance of flexible airfield pavements is simulated by incorporating the permanent deformation of asphalt and granular layers. To achieve accurate predictions, airfield pavements are treated as a unified system, where the total rutting is the cumulative sum of the permanent deformation contributions from each layer.

A nonlinear viscoelastic-viscoplastic model is employed to simulate the response of the asphalt concrete layer, accounting for its time-dependent and plastic behavior. For the granular layers, a modified Drucker-Prager non-associative plasticity model with evolving hardening is utilized. The evolving hardening function captures the microstructural changes in granular materials under cyclic loading, enabling the model to represent the progressive increase in permanent deformation with repeated load applications.

These advanced constitutive models are implemented in the standalone PANDA-AP software (Pavement Analysis using Nonlinear Damage Approach: Airfield Pavements), specifically designed to predict the performance of airfield pavements. Results demonstrate that PANDA-AP effectively predicts both the overall rutting and the layer-specific rutting behavior.

Finally, comparisons are presented between simulations conducted using PANDA-AP and those performed with FAARFIELD software, highlighting the capabilities and differences of these modeling approaches.

Speaker



Masoud Darabi

Associate Professor | University of Kansas

ID 815: Effects of temperature and loading rate on traffic speed deflection measurements

10:50 AM – 11:10 AM

Author(s): Ramez Hajj, University of Illinois Urbana-Champaign

Traffic speed deflection devices have recently gained popularity as a method to assess in-situ structural performance of flexible and rigid pavements. The working principle of these devices is that they use doppler lasers fixed to a fully loaded truck, which applies a moving vehicle load to the pavement, to measure deflection slopes of the pavement surface at different distances from the load application. However, asphalt concrete exhibits a viscoelastic response to this loading. Therefore, the speed at which the truck is moving affects the pavement's response, unlike Falling Weight Deflectometer measurements where loading rate is always constant. However, there are still limited studies conducted which involve correcting for speed. This work, therefore, focuses on applying several time-temperature superposition models to correct the traffic speed deflection models using both measured slopes and computed deflections. The backcalculated modulus values for the asphalt concrete layer are compared for both high and low deflection measurements in various temperature conditions. Furthermore, a framework for measuring temperature, using heat transfer theory, and correcting temperature and speed simultaneously using viscoelastic theory is presented. These works together result in a more robust calculation of in-situ pavement modulus and substantial progress toward utilizing principles of viscoelasticity and heat transfer in these calculations, and therefore more accurate results for inclusion in pavement management systems.

Speaker



Ramez Hajj

Assistant Professor | University of Illinois Urbana-Champaign

ID 841: A Two-Scale Computational Framework to Quantify Effective Oxygen Diffusivity in Asphalt Concrete

11:10 AM – 11:30 AM

Author(s): Masoud K. Darabi, University of Kansas; Bisher Matalkeh, University of Kansas

The oxidative aging of asphalt binder in asphalt mixtures is a primary mechanism governing the long-term durability of flexible pavements. The extent and rate of aging are controlled by oxygen diffusion through the air-void/mastic network and by consumption mechanisms within the binder phase. In this study, a computational method is used to estimate the effective oxygen diffusivity of asphalt concrete by relating it to the phase-specific diffusivities of air voids, aggregates, and asphalt binder. A random particle generation algorithm is used to reconstruct the highly complex structure of Hot Mix Asphalt (HMA) at two representative scales: (a) the meso-scale fine aggregate matrix (FAM), modeled as a two-phase system of fine aggregates dispersed in mastic, and (b) the macro-scale mixture incorporating coarse aggregates, FAM, and air void network. Then, finite-element (FE) diffusion simulations are conducted on the reconstructed geometries, and numerical predictions are systematically compared with relevant analytical solutions and experimental measurements at each scale to estimate the effective oxygen diffusivity. Results highlight the capability of the framework to capture oxygen diffusion in multiphase asphalt composites and to quantify the influence of air-void connectivity and flow paths irregularity (Tortuosity) on estimating the effective oxygen diffusivity.

Speaker



Bisher Matalkeh

PhD Student | University of Kansas

MS 061: Topology Optimization: from Algorithmic Developments to Applications

9:30 AM – 11:30 AM | Location: CASE E240

Chair(s): Mazdak Tootkaboni; Chuan Luo; Josephine Carstensen; Shelly Zhang; James Guest

Moderators



Yash Agrawal

Mr. | Johns Hopkins University

ID 159: Machine Learning-Augmented Human Interaction for High-Performance Topology Optimization

9:30 AM – 9:50 AM

Author(s): Dat Ha, MIT; Faez Ahmed, MIT; Markus Buehler, MIT; Md Ferdous Alam, Georgia Tech; Josephine Carstensen, MIT

Topology optimization (TO) offers significant potential for structural enhancement but remains limited by its 'black-box' characteristics and computational intensity. While human-in-the-loop strategies have been introduced to incorporate expert intuition, they are often stalled by the tedious process of manual region selection. To overcome this, we introduce an AI co-pilot that leverages machine learning to anticipate user preferences for design modification. Using a U-Net architecture trained on synthetic structural data—specifically focusing on topological length and connectivity complexity—our model provides automated recommendations that generalize across diverse design scenarios. Experimental results indicate that this collaborative framework can enhance structural stability by 39% with a negligible increase in design time (15 seconds), offering a scalable path for interactive, high-performance inverse design.

Speaker



Dat Ha

PhD Candidate | MIT

ID 202: Multi-dimensional topology optimization of beams considering sectional-longitudinal coupling

9:50 AM – 10:10 AM

Author(s): Christos Kostopoulos, Columbia University; Ameer Marzok, Technion-Israel Institute of Technology; Haim Waisman, Columbia University

We present a novel concurrent multidimensional topology optimization approach for beams under torsional loading. The proposed formulation considers the coupling between the one-dimensional beam torsion equation in the longitudinal direction, with the two-dimensional warping function equation in the cross-section. The proposed formulation enables the 3D optimization of non-prismatic beams with variable cross-sections, with significantly reduced computational burden compared to full 3D approaches.

The cross-sectional torsional and warping constants are accurately computed utilizing a boundary recognition algorithm, previously developed by the authors. An iterative multidimensional optimization framework is developed in which first, the cross-sectional properties are determined by solving the two-dimensional differential equation. Then, having these properties, the one-dimensional beam equation is solved for the rotations along the beam.

Three different optimization problems are formulated: minimization of rotation compliance under volume constraint, weight minimization under maximum rotation constraint, and weight minimization under maximum von Mises stress constraint. Results reveal generally smooth convergence in simpler cases and more complex patterns in scenarios with stricter constraints or non-uniform loading. Overall, the proposed algorithm provides a general, flexible, and efficient approach for optimizing 3D beam structures subjected to torsion.

Speaker



Haim Waisman

Faculty | Columbia University

ID 246: Topology Optimization Framework for Symmetric Structures: Simple/Multiple Eigenmode Classification and Tracking

10:10 AM – 10:30 AM

Author(s): Shiyao Sun, University of Notre Dame; Kapil Khandelwal, University of Notre Dame

This work introduces a symmetry-informed gradient-based topology optimization framework and computational algorithm focusing on optimizing multiple/repeated eigenmodes (i.e., multiplicities greater than one). The tracking and optimization of multiple eigenmodes has been a major challenge in frequency optimization. Due to the non-uniqueness of multiple eigenmodes, common tracking methods such as the Modal Assurance Criterion (MAC) no longer work. In the past, numerical methods have been developed to address this problem. However, these purely numerical methods failed to account for symmetry as the fundamental cause of multiple eigenmodes in symmetric structures. In contrast, this study adopts a group representation approach that classifies eigenmodes into irreducible symmetry representations, demonstrating that the degeneracy of eigenmodes is not a numerical anomaly but a mathematical characteristic of the eigen spectrum. Robust algorithm is developed to classify and track simple/multiple eigenmodes during optimization.

The framework incorporates symmetry-informed mode tracking with the maximization of eigen-cluster means embedded in a bound formulation, resolving potential challenges due to eigenmode crossings and mode order switches during gradient-based optimization. Furthermore, the cluster mean approach that addresses the non-differentiability of multiple frequencies is refined in this study to incorporate eigenmode classification information. By integrating mathematical insights, this new development transforms the purely numerical clustering into a symmetry-aware tool. The union of the eigenmode classification algorithm and cluster mean method has an additional advantage. To optimize eigenmodes with a specific symmetry, the classification algorithm selects the corresponding eigenfrequency without the need for eigenvector sensitivities, thereby saving computational and memory costs. The improved cluster mean approach subsequently separates truly repeated eigenmodes from numerically convergent ones and ensures the differentiability of the eigenfrequencies corresponding to the target eigenmodes.

Numerical studies are presented to showcase the application of the proposed symmetry-informed optimization framework on complex structures with all common point-group symmetries—including dihedral, tetrahedral, octahedral, and icosahedral groups. The proposed framework is shown to reliably track both simple eigenmodes and multiple eigenmodes with two-, three-, four-, and five-fold degeneracies, demonstrating accurate eigenmode tracking and consistent optimization performance.

Speaker



Shiyao Sun

Ms. | University of Notre Dame

ID 270: Elastoplastic Topology Optimization with Global Enrichment for Thin-Walled Structures

10:30 AM – 10:50 AM

Author(s): Gopal Agarwal, Department of Civil Engineering and Engineering Mechanics, Columbia University; Ameer Marzok, Department of Aerospace Engineering, Technion - Israel Institute of Technology; Haim Waisman, Department of Civil Engineering and Engineering Mechanics, Columbia University

We present an elastoplastic topology-optimization framework for thin-walled prismatic beam structures that maximizes the plastic work (energy absorption) subjected to a volume constraint. The forward analysis relies on small-strain von Mises plasticity with linear isotropic hardening and a return-mapping algorithm solved by Newton–Raphson, considering elasto-plastic beam deformation during bending. To achieve high fidelity on coarse meshes, we enhance the approximation space of the displacement field with XFEM/GFEM global enrichment, augmenting 3D finite elements with a compact set of Euler–Bernoulli vibration modes to capture dominant span-wise axial–flexural behavior. Design variables control the distribution of material over the beam cross-section, which are constant along the beam length. Path dependent gradients are obtained via an adjoint-variable method with a reduced-coaxiality formulation, which aligns the adjoint with the return mapping and avoids explicit tracking of plastic switches, yielding consistent and inexpensive sensitivities. Updates use the Method of Moving Asymptotes with density filtering and projection to produce crisp, constructible layouts.

Numerical studies on extruded beams and panel-stiffener assemblies under monotonic and cyclic loading are expected to have large reductions in degrees of freedom and time-to-solution relative to fine-mesh FEM. These optimized cross-sections would absorb more plastic energy at lower mass delay yield, and improve stability margins compared with baseline elastic designs. The approach provides a scalable, practice-oriented route to performance-based, material efficient design of thin-walled components in the elastoplastic range.

Keywords: FEM; XFEM/GFEM; thin-walled beams; global enrichment; topology optimization; elastoplasticity.

Speaker



Gopal Agarwal

Mr. | Columbia University

ID 431: PDE-constrained optimisation for multiphysics problems with Gridap.jl

10:50 AM – 11:10 AM

Author(s): Connor Mallon, Queensland University of Technology; Zachary Wegert, Queensland University of Technology; Jordi Manyer, Monash University; Santiago Badia, Monash University; Anthony Roberts, Queensland University of Technology; Vivien Challis, Queensland University of Technology

Many problems in science and engineering involve determining unknown parameters that affect system behaviour through physical laws, and are naturally formulated as PDE-constrained optimisation problems. Important examples include topology optimisation, where material distributions are designed to optimise performance, and inverse problems, where parameters are inferred from observations.

Gradient-based optimisation methods are the standard approach for such problems due to the high dimensionality of the design space and the high cost of objective function evaluations, which require the solution of one or more PDE systems. Even with gradient-based methods, PDE-constrained optimisation remains challenging for multiphysics problems, owing to the computational cost of repeated large scale simulations and the complexities of developing problem specific code, especially for computation of the gradient. In many existing approaches, gradients are derived analytically, which is often challenging for multiphysics problems, or rely on finite-differencing when derivatives become complicated [1].

To address these challenges, we develop a PDE-constrained optimisation framework designed to support multiphysics problems with minimal problem-specific effort and with efficiency and scalability as core design objectives. The framework is built on the Julia finite-element library Gridap.jl [2], which combines performance comparable to statically compiled code with a high-level, expressive API.

In alignment with the design principles of Gridap.jl, we provide a syntax to specify arbitrary state equations and objective functions that is near one-to-one with the mathematical notation and implement automatic differentiation tools to eliminate the requirement for user defined gradients. Using an efficient mixed-mode automatic differentiation routine, the cost of a gradient evaluation using the software is comparable to that of a function evaluation for typical cases. For problems where second-order information is beneficial, the framework also supports efficient computation of Hessian–vector products using automatic differentiation, without additional user effort.

Finally, we demonstrate the approach on representative problems, including the topology optimisation a fluid–structure interaction problem using the CutFEM and a contact shape reconstruction problem for a piezoresistive gripper. These applications highlight the ability of the framework to address complex multiphysics PDE-constrained optimisation problems from different domains.

Speaker



Connor Mallon

Queensland University of Technology

ID 495: Level Set Topology Optimization using the Interpolation-based Immersed Finite Element Method

11:10 AM – 11:30 AM

Author(s): Sumedh Soman, University of Colorado Boulder; John Evans, University of Colorado Boulder; Kurt Maute, University of Colorado Boulder

Level Set Topology Optimization (LSTO) coupled with the Immersed Finite Element Method (IFEM) provides a crisp geometry definition for every design iteration while simultaneously avoiding the high computational cost and robustness issues associated with remeshing at every design iteration when using the conventional body-fitted Finite Element Method (FEM). However, converting traditional FEM codes to perform immersed analysis requires invasive modifications, a major barrier in re-purposing existing body-fitted FEM codes for LSTO with IFEM.

To lower this barrier, we propose performing LSTO with the Interpolation-based Immersed Finite Element Method. The Interpolation-based Immersed Finite Element Method allows re-use of existing traditional body-fitted FEM codes for immersed analysis with minimal modifications. Here, we detail the Interpolation-based immersed FEM and derive expressions for design criteria and shape sensitivities of design criteria when performing Level Set Topology Optimization using Interpolation-based Immersed FEM. We present results generated with the proposed Interpolation-based Immersed LSTO framework, utilizing the popular body-fitted FEM code FEniCS for analysis and the CU Boulder code MORIS for geometry discretization. The numerical results demonstrate that the proposed framework is applicable to 2D and 3D problems, yielding high-quality results.

Speaker



Sumedh Soman

Graduate Student | University of Colorado Boulder

MS 058: Origami/Kirigami Inspired Structures and Metamaterials

9:30 AM – 11:30 AM | Location: KTCH 1B87

Chair(s): Evgueni Filipov; John Brigham; Tanmoy Mukhopadhyay; Susmita Naskar; Mark Schenk; Martin Walker

Moderators



Evgueni Filipov

Prof | University of Michigan

ID 16: Kirigami Metastructures for Multidirectional Vibration Energy Harvesting: A Mechanics-Based Investigation

9:30 AM – 9:50 AM

Author(s): Yaowen Zhang, University of Southampton; Susmita Naskar, University of Southampton; Tanmoy Mukhopadhyay, University of Southampton

This study investigates the mechanics of kirigami-inspired three-dimensional (3D) piezoelectric metastructures, focusing on how cut topology controls modal behavior and electromechanical coupling under broadband, multi-axial vibration. Conventional piezoelectric energy harvesters (PEHs) show low modal density and limited directional sensitivity, restricting their effectiveness in complex aerospace vibration environments. Recent studies on graded and fractal architectures have shown that structural topology can tune modal interactions and frequency response [\cite{mondal2025frequency}](#).

A kirigami-based unit-cell design was developed and analyzed through finite-element simulations to study the influence of slit geometry, orientation, and spacing on modal density and inter-modal coupling. Results indicate that kirigami patterning enhances strain localization, modal density, and broadband response, forming a mechanics-informed route to improve electromechanical coupling.

These kirigami-enhanced PEHs can serve as lightweight, passive components for vibration-aware aerospace structures and structural health monitoring. The mechanics principles observed here align with the concept of programmable origami metamaterials that integrate geometry and functional response [\cite{sharma2025tubular}](#).

Speaker



Tanmoy Mukhopadhyay

Senior Lecturer | University of Southampton

ID 17: Folding Intelligence: Magnetically Programmable Bistable Origami Metasurfaces

9:50 AM – 10:10 AM

Author(s): Soumyadeep Mondal, University of Southampton; Tanmoy Mukhopadhyay, University of Southampton; Susmita Naskar, University of Southampton

A strong basis for creating structures with discrete, reversible, and programmed shape alterations is provided by bistability in origami-inspired designs. Using this idea, we present a class of bistable origami metasurfaces that can be magnetically programmed. These metasurfaces represent a type of folding intelligence, which is the capacity to sense, encode, and reconfigure mechanical states via geometric and magnetic interaction.

We build one- and two-dimensional metasurfaces that can undergo multistate reconfiguration by rational tessellation and localised programmable state control, using the waterbomb origami pattern as the basic bistable unit. In order to demonstrate precise control over programmable curvature and morphing behaviour, a far-field magnetic actuation technique is devised to enable contactless, energy-efficient, and spatially selective switching between stable configurations.

The proposed metasurfaces exhibit versatile functionality, including soft robotic untethered locomotion, adaptive gripping, and curvature morphing, all achieved through the distributed coordination of bistable origami units. This magnetically driven folding platform introduces a paradigm of mechanical intelligence, where geometry and actuation coalesce to achieve autonomous, reconfigurable, and multifunctional behaviours. Such systems hold significant potential for next-generation adaptive structures, soft robotics, tunable antennas, energy-efficient grippers, and programmable optical and acoustic devices.

Speaker



Soumyadeep Mondal

phd student | University of southampton

ID 18: Shaping Metasurfaces: Spatially varying origami architecture for Programmable Shape-Morphing Curvatures

10:10 AM – 10:30 AM

Author(s): Aditi Sharma, University of Southampton; Susmita Naskar, University of Southampton; Tanmoy Mukhopadhyay, University of Southampton

The ability of origami-inspired metasurfaces to achieve real-time programmable shape morphing has fuelled a growing interdisciplinary field that explores the controlled transformation of a flat, two-dimensional sheet into complex three-dimensional architectures. This paper proposes a spatially varying origami architecture for achieving programmable shape morphing capabilities. The rigid foldability and motion behaviour of spatially varying origami architecture are examined comprehensively based on computational simulations and tabletop experiments using physical prototypes, demonstrating on-demand shape morphing and precise curvature realisation under minimal actuation. A kinematic mapping framework is developed by modelling the system as an idealised spherical 4R linkage using Denavit–Hartenberg matrix formulations, which facilitates the generation of piecewise spatially graded tessellations capable of producing both symmetric and asymmetric curvatures across complex two- and three-dimensional geometries. Owing to their scale-independent fundamental mechanics, the proposed origami metasurfaces represent a new class of deployable shape-changing architectures with significant potential for a range of technologically demanding space applications such as deployable space structures and antennas, adaptive solar arrays, robotic arms, actuators and advanced robotic materials.

Speaker



Aditi Sharma

Ms | University of Southampton

ID 256: The Flexural Performance of Construction-Oriented Structural Origami

10:30 AM – 10:50 AM

Author(s): Jacob Pavelka, University of Michigan; Sherif El-Tawil, University of Michigan; Evgueni Filipov, University of Michigan

Thick origami-inspired structures have shown potential for a number of applications, including architectural-scale deployable and reconfigurable structures, where panels that make otherwise weak structures can be folded to exploit their in-plane stiffness and make a structure that is stronger and stiffer than the sum of its parts. However, while the kinematics and folding patterns of these origami have been studied thoroughly, their structural properties when made with construction-grade hinges have not. In this presentation, we experimentally analyze the flexural characteristics of thick origami structures constructed with plywood panels and steel piano hinges; a system that could be reasonably used in residential or commercial construction. From our experiments, we find that the additional inter-panel deformation inherent from a discrete hinge connection results in a flexural rigidity that is two orders of magnitude lower than a fully composite value. Furthermore, contrary to the mechanics of thin origami, hinge, panel, and fastener interactions must be explicitly modeled to accurately predict the response of construction-oriented structural origami. Hinge length, number of fasteners, and the type of fasteners were all considered as variables that can affect flexural response, and a finite element model was developed and verified to study the effect of each. We found that hinge length has the greatest influence on strength and stiffness for three-point bending, while the number and type of fastener have a negligible effect. Lastly, we developed additional models to consider multi-hinge configurations, which engaged adjacent panels in flexure more than a single hinge and provided a more robust response to varied loading conditions.

Speaker



Jacob Pavelka

Student | University of Michigan

ID 555: Dual-Surrogate-Assisted Control Co-Design Optimization Framework for Kirigami-Inspired Adaptive Facade

10:50 AM – 11:10 AM

Author(s): Elaheh Mehdizadeh, University of Pittsburgh; Raj Pradip Khawale, University of Michigan; Evgueni Filipov, University of Michigan; John Brigham, University of Pittsburgh

The performance of many adaptive kinetic engineered systems strongly depends on coupled design and operation features. Thus, the optimization of such systems requires a control co-design (CCD) approach that considers both optimal design and control to effectively maximize system performance. CCD optimization problems are often computationally expensive, due to the coupling between design and control optimization, but they can even become computationally prohibitive when high-fidelity simulations are required to evaluate system performance. This work presents a dual surrogate-assisted CCD optimization framework that enables computationally efficient design of adaptive kinetic systems with strongly coupled design and operation features under multiple system conditions. The proposed framework integrates two complementary surrogate models: (i) a performance surrogate model, trained offline to rapidly estimate system performance given design, control, and system condition parameters and (ii) a control surrogate model, iteratively distilled from the performance surrogate model to predict optimal control parameters from design and system condition parameters. By embedding these surrogates within a nested multi-objective CCD optimization structure, the framework dramatically reduces the required number of expensive high-fidelity model evaluations, while also eliminating iterations from the inner control optimization portion of the procedure. The capability of this CCD framework is demonstrated through an example conceptual case study of a kirigami-inspired environmentally adaptive façade component. In this example, the design parameters and daily actuation schedules are estimated to maximize solar energy harvesting and minimize HVAC energy consumption, ultimately maximizing net energy performance for the given building system and environmental conditions. Results show that the proposed approach can accurately identify Pareto-optimal design solution estimates for a CCD optimization problem substantially more computationally efficiently and approximately 80 times faster compared to traditional CCD strategies. Moreover, the framework can be effectively extrapolated to multiple system conditions/scenarios, while considering only a subset of conditions in the first stages of the procedure, to further reduce the required high-fidelity model evaluations. Overall, this work establishes a scalable CCD optimization methodology suitable for complex adaptive engineered systems, providing a practical pathway toward digital-twin-enabled optimization and real-time-capable design of next-generation responsive systems.

Speaker



Elaheh (Eli) Mehdizadeh

Graduate Research Assistant | University of Pittsburgh

ID 667: Mechanical Response of Origami-Based Architected Materials: Effects of Geometry and Material Properties

11:10 AM – 11:30 AM

Author(s): Melika Alavi, Rice University; Larissa Novelino, Rice University

The inherent foldability of origami-based geometries expands the material design space of architected materials, enabling properties such as auxeticity, high deformation recovery, and deployability. One example is the zipper-coupled assembly. This assembly is generated by joining Miura-ori tubes in an aligned and rotated (zippered) fashion. The assembled architecture displays remarkable mechanical properties: anisotropic stiffness and Poisson's ratio, significant shape recoverability, and reversible auxeticity (i.e., the metamaterial switches the sign of Poisson's ratio during deformation). In this work, we demonstrate that the unique behavior of the zipper-coupled assembly can be achieved at the millimeter scale using fused deposition modeling (FDM) and a variety of polymers. Specimens were fabricated from three thermoplastics: polylactic acid (PLA), polyethylene terephthalate glycol (PETG), and thermoplastic polyurethane (TPU). Each assembly was printed with a uniform 1 mm panel thickness and at three folding angles ($\psi = 35^\circ, 40^\circ, \text{ and } 55^\circ$), representing distinct deployment states. Quasi-static compression tests were conducted in all three principal directions (X, Y, and Z). The X-direction is defined along the length of the Miura tubes, and Y- and Z-directions are defined on the cross-section of the tubes. The tubes are aligned along the Z-direction and zipper-coupled along the Y-direction.

Our results show the expected geometrically designed anisotropy. The non-foldable Z-direction tended to exhibit the highest stiffness, reaching approximately twice the X-direction modulus and up to 35 times the Y-direction modulus at $\psi = 35^\circ$. The foldable X- and Y-directions exhibited opposite trends with folding angle: X-direction stiffness decreased with increasing ψ , while Y-direction stiffness increased. In terms of energy absorption, at low folding angles ($\psi = 35^\circ$), the X-direction shows the highest energy absorption capability independent of the material. With an increase in folding angle, while the energy absorbed in the X-direction decreased, the absorption capacity in the Y- and Z-directions increased. The trends indicate that the preferred direction of energy dissipation can be programmed by selecting deployment states.

The findings establish a geometry-to-material framework linking folding angle and constitutive response to directional stiffness and energy absorption. Qualitative trends in anisotropy persist across all polymers. This presented work enables the prediction of directional properties for origami-inspired metamaterials across material systems, supporting their application as tunable, load-bearing energy absorbers in deployable structures.

Speaker



Larissa Novelino

Assistant Professor | Rice University

MS 064: Structural Identification and Damage Detection

9:30 AM – 11:30 AM | Location: GUGG 205

Chair(s): Eleni Chatzi; Eleonora Tronci; Babak Moaveni; Costas Papadimitriou; Zhilu Lai

Moderators



Eleonora Maria Tronci

Assistant Professor | New York University

ID 105: Interpretable β -Variational Autoencoders for Discovering Higher-Order Sensitivities in Nonlinear Hysteretic Structures

9:30 AM – 9:50 AM

Author(s): Reza Farzad, University of Notre Dame; Patrick Brewick, University of Notre Dame

Hysteretic structural systems exhibit highly nonlinear behaviors governed by parameter interactions, creating challenges for traditional sensitivity analysis methods, especially when higher-order effects dominate. On the other hand, while traditional methods such as PCA (Principal Component Analysis) only captures the compact linear representations of data, Autoencoders (AEs) and Variational Autoencoders (VAEs) capture the nonlinear latent space of data through a designed neural architecture. This work introduces a β -Variational Autoencoder (β -VAE) framework that learns low-dimensional, interpretable latent representations of nonlinear hysteretic responses and reveals the dominant parameter interactions that drive the dynamic response behavior. Using simulated response data from a multi-story base-isolated building subjected to non-stationary ground motions, we demonstrate that the β -VAE reliably compresses base displacement trajectories into a few (linearly) disentangled latent variables, each aligning with distinct physically meaningful generative factors. A β -annealing strategy is proposed to control latent-space sparsity and sequentially extract salient combinations of generative factors that arise from either structural parameters, excitation parameters, or the joint interaction of both structural and excitations parameters. We complement this with correlation analysis as well as multiple linear regression analysis to further identify salient parameter combinations each latent variable represents. Moreover, thanks to the generative nature of VAEs, Sobol' sensitivity analysis has been implemented on the decoder part of the network to quantitatively rank the latent variables in terms of their contributions in the reconstruction process. Through a series of examples that consider uncertainty in the structural and excitation parameters, both separately and jointly, we show that the β -VAE uncovers stiffness-strength axes, duration-frequency controlled excitation modes, and higher-order cross-domain interactions that cannot be easily isolated by conventional Sobol' indices. These results highlight the potential of VAEs as data-driven yet interpretable tools for nonlinear system analysis, offering a pathway toward model-order reduction, feature discovery, and future physics-integrated learning strategies in structural dynamics.

Speaker



Reza Farzad

PhD Candidate | University of Notre Dame

ID 258: Adaptive Covariance Selection for Filter-Based Joint Input-State Estimation of Hysteretic Structures

9:50 AM – 10:10 AM

Author(s): Tae-ha Kim, Seoul National University; Sang-ri Yi, Rice University; Junho Song, Seoul National University

Real-time applications in structural engineering, such as health monitoring and structural control, critically depend on the accuracy of information regarding input forces and structural responses. In this context, joint input-state estimation plays a key role by enabling the identification of unmeasured input forces and system states. For example, we recently developed a filter-based joint input-state estimation method for hysteretic structures using noisy and partial measurements by modeling the time derivative of the force as a zero-mean Gaussian process. However, filter-based approaches are typically limited by their reliance on heuristic tuning of parameters, including noise covariances. Especially, the challenge of determining effective covariances intensifies as the input-state dimension grows. To address these challenges, this study proposes an adaptive noise covariance matrix selection method that updates the covariance at each time step for joint input-state estimation of hysteretic structures. By interpreting the model noise covariance as the stochastic discrepancy between the true latent state and the model-based predicted state, the covariance matrix is adaptively updated using the Kalman gain and measurement innovation during the correction step of the Kalman filter. For robust tuning of covariance, the proposed method updates the force process covariance using the calculated covariance while keeping the state noise covariance fixed. Furthermore, a moving average strategy of the estimated covariance is applied over time to mitigate the bias introduced by measurement noise. By updating the noise covariance at each time step, the proposed method allows the model to adapt flexibly to the time-varying dynamics of nonlinear structures and enables the accurate estimation of real-time input and state estimation for high-dimensional input-state spaces. The effectiveness and robustness of the proposed method are demonstrated through numerical examples involving bilinear and Bouc-Wen hysteretic structures. Additionally, a case study of a 9-story benchmark building, in which the target structure differs from the known model is performed to investigate the real-world applicability of the proposed methods. The proposed method successfully enhances the applicability of joint input-state estimation to the real-world scenarios by maintaining consistent prediction performance for nonlinear and hysteretic systems.

Speaker



Tae-ha Kim

Graduate Student | Seoul National University

ID 355: A Bayesian Inference Approach for Site Characterization Using Surface Wave Measurements

10:10 AM – 10:30 AM

Author(s): Koosha Raisi, Tufts University; Babak Moaveni, Tufts University; Laurie Baise, Tufts University

A Hierarchical Bayesian model inversion method is developed for site characterization and site response prediction using surface wave measurements and H/V spectral ratios. The hierarchical Bayesian method estimates a shear velocity profile with uncertainty quantification using both surface wave-derived dispersion curves and ambient noise-derived H/V spectral ratios. In the proposed framework, conjugate prior distributions are assumed for the shear wave velocity in each soil layer. The prior probability distributions of shear wave velocities are updated to their posterior distributions through the Hierarchical Bayesian Inference, where the mean and covariance of the model parameters are estimated as hyperparameters. The Metropolis-Hastings algorithm and the Gibbs sampler are used for estimating the updating parameters and hyperparameters. The framework is initially evaluated numerically when applied to a simulated model of a 4-layer soil profile. The accuracy of the proposed inversion process is compared with that of the classical Bayesian Inversion for different amounts of available data, and the effects of adding fundamental frequency terms from H/V data are investigated. The updated soil profiles are then used to estimate the site response transfer function and its uncertainty bounds. The proposed inversion process is evaluated experimentally using field measurements at a site in the greater Boston area. The hierarchical Bayesian inference approach provides a mechanism to use both the dispersion curve and the H/V spectral ratio in the shear wave velocity inversion. The estimated uncertainty of model parameters and modeling errors is used to provide uncertainty bounds for the predicted site response transfer function. The estimated uncertainty bounds derived from the Hierarchical Bayesian approach, using dispersion curves and H/V spectral ratios, are more realistic than those obtained from the classical Bayesian inference, due to its capability to effectively quantify uncertainty.

Speaker



Koosha Raisi

Research Assistant | Tufts University

ID 440: Model Updating under Multi-Setup Conditions using NExT-based Unscented Kalman Filter in Ambient Excitation

10:30 AM – 10:50 AM

Author(s): Wonhui Goh, Seoul National University; Yunbyeong Chae, Seoul National University

Structural model updating based on ambient vibration measurements is an essential component of structural health monitoring for civil infrastructures. In many field applications, however, reliable parameter estimation is challenging because the excitation forces are unknown and the measured responses often exhibit low signal-to-noise ratios. These difficulties are further amplified in multi-setup testing, where different sensor layouts are used sequentially and only partial measurements are available in each setup. This study proposes a robust time-domain model updating framework for multi-setup ambient vibration data by integrating the Natural Excitation Technique (NExT) with an Unscented Kalman Filter (UKF).

The framework first employs NExT to convert ambient acceleration measurements into virtual impulse response functions (VIRFs) using correlation-based processing. This transformation enables the use of free-decay-type information while avoiding the need for explicit input force measurements, allowing parameter updating to be performed directly in the time domain. The proposed UKF formulation then updates structural stiffness-related parameters by matching measured and simulated VIRF segments. To improve robustness in the presence of noise and limited data length, the updating procedure is performed in a windowed manner, and practical stabilization steps are introduced to reduce sensitivity to window-to-window variations. In particular, the method is designed to prevent errors associated with the beginning of each window from being incorrectly interpreted as parameter changes, which is a common source of bias in time-domain updating when free-decay signals are used.

A key feature of the proposed approach is its suitability for multi-setup conditions, and its performance is validated using a numerical Warren-type planar truss example under ambient excitation. Data from different reference configurations are treated as complementary sources of information, and the framework sequentially integrates these virtual experiments to estimate a single global parameter set. As a result, the method can leverage diverse measurement perspectives while maintaining a unified updating process, without requiring explicit assembly of mode shapes or full-field measurements. The study also examines, in a practical sense, how analysis settings such as window duration and segmentation choices influence convergence behavior under high-noise conditions.

Overall, the proposed NExT-based UKF framework provides a practical and robust option for stiffness model updating using ambient vibration data under multi-setup and partial-measurement scenarios. The method is intended to support field-oriented applications where measurement noise, unknown excitation, and changing sensor configurations are unavoidable.

Speaker



Wonhui Goh

Seoul National University

ID 647: A novel, consistency-based metric for probabilistic remaining useful life model selection

10:50 AM – 11:10 AM

Author(s): Dongjin Du, Vanderbilt University; Pranav Karve, Vanderbilt University; Sankaran Mahadevan, Vanderbilt University

Physics-based, data-driven, and hybrid models are used for remaining useful life (RUL) prediction in various engineering applications. These models are usually calibrated using data obtained from accelerated material failure tests. The calibrated RUL model is, however, used to predict material performance under normal operating conditions. Normal operating conditions are significantly different than the accelerated test conditions, and material failure data under normal operating conditions is not available in many cases. Due to the lack of material failure data, validation metric-based model selection is not applicable for those pipes. To tackle the problem of choosing the best probabilistic RUL prediction model for such extrapolation situations, a model consistency-based metric is proposed in this research. The proposed metric evaluates the inconsistency in the probabilistic RUL prediction model under the variability in normal operating conditions. Specifically, it measures the dissimilarity between the family of RUL probability distributions corresponding to the (joint) probability distribution of operating conditions. The Jensen-Shannon divergence (JSD) is used for quantifying the distance between two RUL probability distributions. A larger JSD between RUL at a possible operating condition and RUL at the mean operating condition indicates higher degree of inconsistency in the RUL prediction model (compared to other RUL models). The mean JSD value for the given (estimated) probability distribution of the normal operating condition is used as a scalar metric quantifying the model consistency.

A two-step approach, which considers model validation as well as model consistency, is proposed for model selection. In the first step, model validation is performed using previously developed metrics and accelerated test data. In the second step, model consistency is evaluated for the normal operating conditions. The model with superior performance in both these steps is chosen to be the best RUL prediction model.

The proposed methodology is demonstrated by performing calibration and validation for five RUL models for polyethylene (PE) pipes. Bayesian inference is used to calibrate these models with empirical data, and its benefit over the least squares approach recommended in ISO 9080 is demonstrated. The model reliability metric is used to validate these models. Finally, the proposed two-step model selection methodology is used to select the best model. Results indicate that different models may exhibit similar validation performance under accelerated testing but substantially different levels of prediction consistency under operational uncertainty. The performance of the proposed model selection method is compared against traditional model selection methods (goodness of fit, model complexity and information theoretic metrics). The proposed methodology is applied to different normal operating conditions, and it is shown that different models could be more consistent in predicting PE pipe RUL under these circumstances. It is also shown that the proposed additional consistency criterion is useful for selecting the best RUL prediction model in these, practically relevant, scenarios.

Speaker



Dongjin Du
Vanderbilt University

ID 880: Monitoring of Music-Induced Vibrations in the National Gallery

11:10 AM – 11:30 AM

Author(s): Will Owens, Department of Engineering Science, University of Oxford; Catherine Higgitt, Scientific Department, The National Gallery, London, UK; Manolis Chatzis, Department of Engineering Science, The University of Oxford

Vibration-induced mechanical stress constitutes a significant threat to canvas paintings within museums and galleries. As heritage institutions diversify the usage of their spaces to increase engagement and revenues, the risk of direct exposure to sound-induced vibrations, e.g., due to music, increases. However, the impact of such exposure is not well understood, limiting the ability of curators and conservators to make informed decisions about how a collection should be protected. In this work, the results obtained during a monitoring campaign at the National Gallery, London—are presented.

The sensor setup comprises an array of high-sensitivity microphones and accelerometers to simultaneously capture the acoustic pressure field in the galleries and the vibrational response of their walls of display. The results from two study cases obtained within the same display gallery are discussed. In the first case, data were acquired during a live event comprising an oral presentation, music by a live choir and a fully populated room. For the latter case, data were obtained during a structured investigation, where controlled inputs from specific musical instruments were used with only the musicians in the display gallery. The instruments and the music content performed were selected to cover a broad range of frequencies and timbres.

The two case studies reveal a series of useful findings. The former demonstrates that the acoustic field is relatively homogeneous throughout the space in the low-frequency range, whereas the vibrational response of the walls is highly heterogeneous and location-dependent. This suggests that the acoustic input may be monitored with a sparser sensor array, but that accurately capturing the vibrational response requires a larger array of carefully placed sensors. The latter case investigates the direct correlation between specific acoustic sources and wall vibration; this allows for a quantitative comparison contrasting instruments dominated by high-frequency content with lower acoustic pressure, such as violins, against those generating high acoustic pressure capable of driving low-frequency structural dynamics, such as brass instruments. This work investigates which of these sources can be more detrimental to the paintings in the gallery due to the corresponding induced stresses.

In both cases, a stochastic system identification (SSI) algorithm is applied to estimate the vibro-acoustic properties of the display gallery. A challenge in this application for Structural Health Monitoring algorithms is that the construction details of the walls of the room are not known due to the rich history of the National Gallery, and that the acoustic excitations result in small amplitude vibrations. To overcome those challenges the SSI algorithm *n4sid* is employed together with advanced stabilization algorithms. The simultaneous logging of both the acoustic source and the acceleration outputs allows for investigating the use of the method in both input-output and output-only modes. The results provide a definitive, data-driven characterisation of the structure of the display gallery, and enable the further investigation of the effects of the vibrations on the paintings of the display gallery. They further establish a foundation for future virtual sensing models to estimate the vibrational response at unmeasured locations from limited measured signals. Additional findings of interest to both the engineering and conservation communities will be presented during the conference.

Speaker



Emmanouil Chatzis
Oxford

MS 068: Surrogate Modeling for Uncertainty Quantification, Optimization, and Statistical Inference in Engineering Applications

9:30 AM – 11:30 AM | Location: ECON 119

Moderators



Alexandros Taflanidis

Professor | University of Notre Dame

ID 149: Adaptive and Uncertainty-Aware Surrogate Modeling for Reliability Analysis of Nonlinear Dynamic Systems

9:30 AM – 9:50 AM

Author(s): Zhiwei Wang, University of Michigan-Dearborn; Michael D. Todd, University of California San Diego; Zhen Hu, University of Michigan-Dearborn

Reliability analysis of nonlinear dynamic systems under uncertainty remains a critical yet challenging task. Traditional methods, such as Monte Carlo simulation (MCS) and analytical approximations, often suffer from limited accuracy and high computational cost, particularly when dealing with high-dimensional nonlinear dynamic systems subjected to stochastic excitations. The path-dependent nature of dynamic responses, combined with the high dimensionality arising from discretized excitation time histories and uncertain system parameters, poses significant obstacles for conventional surrogate modeling approaches.

This study develops an adaptive and uncertainty-aware surrogate modeling framework for reliability analysis of nonlinear dynamic systems subjected to stochastic excitations. The proposed method employs an attention-enhanced long short-term memory (aLSTM) encoder combined with a spectral-normalized neural Gaussian process (SNGP) predictor to form an uncertainty-aware surrogate model (aLSTM-SNGP). The aLSTM encoder captures complex temporal dependencies in stochastic excitation sequences while implicitly performing dimensionality reduction, and the SNGP predictor provides calibrated predictive uncertainty estimates. Both modules are jointly optimized through a co-training strategy, ensuring that learned feature representations are directly aligned with predicting extreme dynamic responses. This surrogate model directly predicts the maximum structural response and its associated uncertainty, thereby avoiding costly nonlinear time-domain simulations. Two failure probability estimation methods are developed based on the trained surrogate model: a direct MCS approach and an importance sampling (IS) approach with adaptive proposal density construction via particle filtering. An active learning strategy is employed to iteratively identify the most informative samples for surrogate refinement, combined with a hybrid training scheme that balances global accuracy and local refinement near the failure boundary. Numerical studies on nonlinear shear-building models with Bouc-Wen hysteretic behavior under nonstationary stochastic seismic excitations demonstrate that the proposed framework provides accurate failure probability estimates with greatly reduced computational cost compared to direct MCS. The results highlight the potential of integrating advanced surrogate modeling and adaptive sampling strategies for reliability analysis of complex structural systems.

Speaker



Zhiwei Wang

Research Fellow | University of Michigan-Dearborn

ID 214: Neural Operator-based Fatigue Reliability Analysis of Floating Offshore Structures under Wave-Induced Excitations

9:50 AM – 10:10 AM

Author(s): Wangyu Choi, Seoul National University; Jungho Kim, Sejong University; Seonghyun Lim, Rice University; Junho Song, Seoul National University

Floating offshore structures have attracted increasing attention as a viable and flexible solution for the efficient utilization of offshore space, providing additional options for deploying large-scale infrastructure systems in the marine environment. As offshore space is increasingly recognized as a valuable extension of available engineering domains, floating systems offer structural adaptability and scalability that can accommodate diverse functional requirements under varying site conditions. However, these structures are inevitably subjected to environmental loads, particularly wave-induced excitations, which can lead to fatigue damage in critical components such as mooring lines and structural connectors. Conventional fatigue damage assessment approaches mainly rely on frequency-domain analysis based on power spectral density functions derived from random vibration theory. While computationally efficient, such approaches typically rely on narrowband assumptions and thus have limited capability in capturing nonlinear responses and multi-peaked characteristics commonly observed in realistic offshore environments. To overcome these shortcomings, time-domain fatigue analysis directly exploits full response trajectories, enabling the consideration of nonlinear and non-stationary effects. However, obtaining sufficiently long response time histories through high-fidelity finite element simulations remains computationally prohibitive, particularly for reliability assessment requiring repeated evaluations. To address the challenge, this study employs a neural operator-based surrogate model to efficiently generate structural response trajectories with significantly reduced computational cost. The predicted responses are subsequently processed using the rainflow counting algorithm to extract stress cycles, followed by fatigue damage estimation based on Miner's rule, in which fatigue failure is defined as the exceedance of cumulative damage over the prescribed fatigue capacity. The proposed framework enables rapid and accurate quantification of fatigue demands in floating offshore structures, thereby supporting risk-informed decision-making through efficient evaluation across diverse loading scenarios, structural configurations, and operational conditions over the service life.

Speaker



Wangyu Choi

University Researcher | Seoul National University

ID 255: Active Subspace Dimension Reduction for Surrogate Modeling in UQ

10:10 AM – 10:30 AM

Author(s): Promit Chakroborty, Vanderbilt University; Ramesh Babu J., University of Oklahoma; Pranav Karve, Vanderbilt University; Sankaran Mahadevan, Vanderbilt University

Computer simulation models are an essential tool for solving high-consequence performance analysis and design tasks for complex physical systems (such as materials fabrication for aerospace applications). However, high-fidelity simulation models are computationally intensive and may contain a large number of imperfectly known parameters. This makes their use in uncertainty quantification (UQ) challenging under practical time or budget constraints. Further, inference and forward propagation require considering high-dimensional parameter spaces, which is well known to be intractable for most UQ analysis tools. Instead, if the many parameters can be represented using a much smaller number of latent variables with a minimal loss of information (a.k.a., Dimension Reduction), standard sampling and estimation techniques for UQ become viable. Also, surrogate modeling techniques (e.g., Gaussian Process Regression, Polynomial Chaos Expansion, etc.) can be leveraged in the latent space to create fast-running approximations of the complex physical system, which may not be possible with the original set of inputs due to the curse of dimensionality suffered by most regression techniques.

The method of Active Subspaces (AS) attempts to find a low-dimensional representation of the model parameters by using gradient information to infer linear combinations of the original input parameters that affect the model output the most, i.e., the directions in the parameter space along which the model changes the most on average. A central question to AS implementation is choosing an appropriate number of directions. The traditional method of doing so (as presented by Constantine [1]) only explicitly considers the accuracy in estimating the directions, but not the model prediction error introduced by dropping the unselected directions. Further, the procedure relies on derivative-based sensitivity information (commonly referred to as DGSM) along the discovered directions; it has been long-observed that DGSM can be misled when the studied variables are combined with high nonlinearity. This can lead to some directions receiving overly heightened importance, causing other important directions to seem negligible by comparison.

In this presentation, we explore the question of selecting directions from a practical perspective, by studying a crystal plasticity finite element model of Ti-6Al-4V with 11 parameters. Through comparisons with Sobol' sensitivity indices and surrogate-approximated reconstruction error, we investigate the sufficiency of the usual AS direction selection scheme and provide alternative heuristics for improved performance. In addition, we develop interesting insights about the important parameters governing the stress-strain behavior of the Ti-6Al-4V alloy.

References:

[1] Constantine, P.G.; Active Subspaces: Emerging Ideas for Dimension Reduction in Parameter Studies; SIAM Spotlights (2015)

Speaker



Promit Chakroborty

Postdoctoral scholar | Vanderbilt University

ID 272: PINN-DGP: Coupling Physics-Informed Neural Networks with Deep Gaussian Processes for Uncertainty-Calibrated Parameter Discovery

10:30 AM – 10:50 AM

Author(s): Boyuan Deng, Johns Hopkins University; Hongyang Zhang, The Hong Kong Polytechnic University; Kshitiz Upadhyay, University of Minnesota; Michael Shields, Johns Hopkins University

Estimating parameters from sparse, noisy, and multi-fidelity data remains a core challenge in scientific machine learning (ML), particularly in domains like materials science where direct observations are limited and physics-based models must bridge the gap. We introduce PINN-DGP, a novel hybrid framework that couples Physics-Informed Neural Networks (PINNs) with Deep Gaussian Processes (DGPs) to enable robust parameter estimation with calibrated uncertainty quantification. By repurposing PINNs as physics-constrained generators, our approach produces auxiliary parameter samples that augment scarce high-fidelity observations, refining a pre-trained DGP surrogate model without overwhelming reliable data.

PINN-DGP is organized as a recursive, closed-loop update that explicitly respects fidelity hierarchies. We first pre-train the DGP surrogate on available high-fidelity parameter measurements, yielding a probabilistic prior over the unknown parameter function and a principled representation of epistemic uncertainty under data scarcity. During physics-informed training, the surrogate's predictive mean is injected into the PINN residual, so PDE enforcement is performed using the current best estimate of the parameter rather than treating it as fixed or directly optimizing it as a network weight. After a prescribed number of iterations, the PINN generates physically consistent auxiliary parameter samples, which are used to refine the surrogate while preserving the influence of the original high-fidelity data.

We validate the framework on the viscous Burgers' equation, targeting the reconstruction of time-dependent kinematic viscosity functions from sparse, noisy measurements. In this regime, standard Gaussian Processes can overfit because sparse observations weakly constrain kernel hyperparameters, while vanilla DGPs can be overly conservative, yielding wide confidence intervals. PINN-DGP addresses both limitations by combining scarce high-fidelity parameter measurements with lower-fidelity PDE constraints: PINN-generated, physics-consistent auxiliary samples selectively densify the parameter space without diluting trusted data. Across representative viscosity profiles, the hybrid framework achieves mean squared error reductions of up to 79% in parameter inference relative to GP and DGP baselines, while producing uncertainty bands that are better aligned with observed error levels. This capability is critical for resource-constrained engineering applications, such as ex vivo tissue testing or destructive material evaluation, where data are inherently scarce and uncertainty-aware decisions are essential.

Speaker



Boyuan Deng

PhD Candidate (Student) | Johns Hopkins University

ID 472: A stochastic emulator framework for high-dimensional reliability-based design optimization

10:50 AM – 11:10 AM

Author(s): Maliki Moustapha, ETH Zurich; Jaad Bel Houari-Durand, ETH Zurich; Bruno Sudret, ETH Zurich

Design optimization plays a central role in ensuring that engineering structures are both optimal and robust to the presence of uncertainty. These uncertainties may stem from the design itself, for instance due to manufacturing tolerances or material variability, or from the operating environment (e.g., uncertain loads). Reliability-based design optimization (RBDO) provides a rigorous framework to address these challenges by explicitly trading off design cost against a prescribed target reliability level.

While conceptually appealing, RBDO problems remain challenging to solve in practice. The main difficulty lies in the computational burden, as a reliability analysis must be carried out for each candidate design encountered during the optimization process. This typically results in a prohibitively large number of model evaluations, which is intractable when the underlying simulator is expensive. Surrogate models are often introduced to alleviate this cost. However, classical deterministic surrogates tend to lose efficiency and accuracy as the dimensionality of the input space increases.

In this contribution, we present an alternative RBDO framework based on stochastic emulators, which are surrogate models specifically designed to approximate stochastic simulators response distributions. In contrast to deterministic ones, stochastic simulators produce different outputs when evaluated multiple times at the same design point, due to intrinsic sources of variability that are beyond the designer's control.

The proposed approach starts by reformulating the RBDO problem through a clear separation of the model inputs into deterministic design variables and random variables describing uncertainty. The latter are aggregated into a set of latent variables, which are integrated out such that the model response at each design point becomes a stochastic quantity. This stochastic response is then approximated using stochastic emulators, such as stochastic polynomial chaos expansions (SPCE) [1] or generalized lambda models (GLaM) [2]. This formulation implicitly achieves dimensionality reduction by representing the influence of numerous random variables through a latent structure. In addition, the resulting stochastic surrogate directly provides the conditional output distribution, enabling semi-analytical evaluation of reliability metrics without repeated and computationally expensive reliability analyses throughout the optimization process.

The effectiveness of the proposed framework is demonstrated through several application examples, including problems of moderate and high dimensionality. These examples highlight the potential of stochastic emulators as a powerful tool for scalable and efficient reliability-based design optimization.

References

[1] Zhu, X. and B. Sudret (2023). Stochastic polynomial chaos expansions to emulate stochastic simulators. *International Journal for Uncertainty Quantification*, 13(2), 31–52.

[2] Zhu, X. and B. Sudret (2021). Emulation of stochastic simulators using generalized lambda models. *SIAM/ASA Journal on Uncertainty Quantification*, 9(4), 1345–1380.

Speaker



Bruno Sudret

Faculty | ETH Zurich

ID 503: Adaptation of Stochastic Emulation to Shift of Distribution

11:10 AM – 11:30 AM

Author(s): Seonghyun Lim, Rice University; Sang-ri Yi, Rice University

Gaussian processes (GPs) have been widely used as surrogate models for stochastic emulation. However, conventional GP and other stochastic emulator formulations assume that the distribution of data at test remains the same as during training. This assumption imposes limitations on the reuse of existing surrogates when the underlying stochastic description of the system is updated. To address this limitation, this study proposes a concept-shift-aware stochastic emulation framework that enables consistent prediction of distribution under updated implicit (aleatoric) input distributions without repeating the entire training process. The key concept is to interpret the shift in the distribution as a reweighting of the training samples and to develop a quick prediction formulation under the new sample weights. In particular, we build on the GP-based stochastic emulator and reinterpret the nugget term as an uncertainty adjustment mechanism by introducing virtual replication points for training samples with higher weights. The effective replication counts are constructed using importance weights derived from the ratio of the updated to the original input probability densities. The resulting GP covariance structure achieves a balance between interpolation accuracy and nugget-based smoothing when the training data becomes partially misaligned with the target distribution, as may occur under concept shifts. The proposed approach is demonstrated using a cantilever beam example with spatially varying material properties modeled as a random field. Results show that the method accurately reproduces distribution predictions without needing to re-train the emulator under the updated distribution, while maintaining numerical stability and physical interpretability in terms of effective sample size. The proposed framework offers a computational strategy that is both efficient and interpretable in terms of updating stochastic emulators in the context of evolving uncertainty descriptions.

Speaker



Seonghyun Lim

Postdoctoral Associate | Rice University

MS 074: Innovations in CFD and FSI: Rigorous Methods with Practical Applications

9:30 AM – 11:30 AM | Location: CHEM 140

Chair(s): Yuri Bazilevs; Ming-Chen Hsu; Artem Korobenko; Georgios Moutsanidis; Jinhui Yan

Moderators



Yuri Bazilevs

Prof. | Vanderbilt University

ID 23: Preliminary Simulation of Thermal and Structural Behavior in Toroidal Combustion Systems

9:30 AM – 9:50 AM

Author(s): Domingo Fontiveros, Florida International University; Sean Khan, Florida International University; Andres Tremante, Florida International University

The toroidal combustion architectures offer continuous-motion alternatives to conventional reciprocating engines but introduces complex thermo-mechanical loading that remains poorly quantified. This work presents a combined CFD and FEA study of transient heat transfer, pressure generation, and structural response within a simplified toroidal combustion chamber segment ("donut engine"). Using ANSYS finite-volume simulations with ideal-gas air, NASA-9 thermophysical properties, and a time-dependent ignition heat flux, we compute spatially resolved temperature fields exceeding 2.5×10^3 K within $O(10^{-2}$ s). The induced pressure loads drive bending-dominated stresses in a radial piston/rod subassembly, analyzed through a linked static-modal-harmonic finite element workflow. Peak von Mises stresses approach 2.5 GPa in the simplified geometry, and harmonic analyses reveal the first bending modes occurring in the ~ 12.7 kHz range. The results highlight the strong multiphysics coupling inherent to toroidal combustion chambers and provide early design guidance for geometry refinement, material selection, and load mitigation. The study demonstrates a reproducible computational framework for screening unconventional combustion-driven mechanical systems and aligns with ongoing efforts in CFD-FSI methodology for complex, transient, thermally driven structures.

Speaker



Sean Khan

Student | Florida International University

ID 84: Rheology of dense fiber suspensions

9:50 AM – 10:10 AM

Author(s): Arezoo Ardekani, Purdue University

We develop a high-fidelity computational model of fiber suspension to investigate suspension rheology. We investigate the interplay between the hydrodynamic, noncontact attractive and repulsive, and interfiber contact interactions. The shear-thinning viscosity and finite yield stress obtained from the Immerse Boundary Method simulations align quantitatively with experimental findings from the literature. The study demonstrates that attractive interactions lead to both yield stress and shear thinning behavior in fiber suspensions. This discovery holds significance as it contributes to the ongoing debate on the source of yield stress in fiber suspensions. The proposed model is used to quantify normal stresses in addition to shear thinning and yield stress.

Speaker



Arezoo Ardekani

Professor | Purdue University

ID 134: Simulation of hydrodynamic loading on navigation lock miter gates

10:10 AM – 10:30 AM

Author(s): J. Ezequiel Martin, Coastal and Hydraulics Laboratory - US Army Engineer Research and Development Center; Christopher R. Denney, Coastal and Hydraulics Laboratory - US Army Engineer Research and Development Center

Miter gates are an essential part of the US riverine navigation system. The US Army Corps of Engineers is tasked with the design, maintenance and operation of these structures. Earlier than expected failure in gate anchorage and pin connections of some direct-connected hydraulic machinery installed in past rehabilitations highlight the need for better understanding of the dynamics of these systems. In addition, dated design guidelines lacking modern validation and that do not encompass all configurations current in use limit the applicability of those guidelines. A multi-approach investigation, including numerical simulation, laboratory experimentation and field data collection, is on-going to update the understanding on load predictions in the system. Approach and results for the computational fluid dynamics part of this effort will be presented. The open-source solver OpenFOAM is used to simulate the operation of the miter gates. High-fidelity simulations are used to simulate the free surface flow generated by the gate motion, as well as the spatial and temporal distribution of hydrodynamic forces on the gate. These loads are then used to inform and analyze fatigue in anchorages and pin connections for the direct-connected machinery and other configurations namely, direct hydraulic, Panama, and modified Ohio. Various gate operating speeds, linkage profiles, and submergences are assessed. The overset interpolation is required for these cases due to the large displacement of the gates. The presence of small gaps in the system (between the two gate leaves, and the gates and lock sills when closed, and between the lock wall and the gate when open) are also a challenge for these cases and require a careful approach to meshing and modeling to preserve the quality of the simulations.

The methodology used, including modifications needed to improve the current overset model in OpenFOAM, as well as results for initial validation of the model with available data from a 1964 Waterways Experimental Station report will be presented.

Speaker



Ezequiel Martin

Research Engineer | ERDC-USACE

ID 145: The monolithic finite element method for CFD simulations: from bio-inspired fliers to soccer ball aerodynamics

10:30 AM – 10:50 AM

Author(s): Jinhui Yan, University of Illinois Urbana Champaign

The talk will present a monolithic overset framework for high-fidelity simulation of turbulent flows around complex structures undergoing large relative motions, based on finite element discretizations of the incompressible Navier–Stokes equations. Traditional overset methods, which typically rely on the Schwarz Alternating Method (SAM), require iterative coupling between overlapping subdomains and often encounter convergence issues. In contrast, the proposed approach reformulates the overset problem as a single unified system. Continuity across overlapping regions is enforced through Dirichlet boundary conditions and incorporated directly into the nonlinear residual evaluation, eliminating subdomain iterations and enabling a practical monolithic solution strategy. To support efficient large-scale parallel computations, two additional techniques are introduced. First, an octree-accelerated node-location algorithm is developed for rapid solution projection between subdomains. Second, because the overlapping meshes are not conforming, we design a parallel GMRES solver equipped with a composite, partially matrix-free formulation to handle the global linear systems. This framework simultaneously maintains a boundary-fitted mesh representation for the fluid-structure interface and handles complex structures with arbitrary motion in the flow. Verification is performed using a benchmark Burgers' equation problem, followed by a comprehensive assessment under varying spatial resolutions, time-step sizes, and overlap extents. Finally, we demonstrate the method's capability to address real-world applications through simulations of a bio-inspired hybrid flier system and full-flight soccer-ball aerodynamics.

Speaker



Jinhui Yan

Associate Professor | University of Illinois Urbana Champaign

ID 192: OpenFSI–Magttice: A Scalable Lattice-Based CFD/FSI Platform for Magneto-Active Soft Structures and Underwater Locomotion

10:50 AM – 11:10 AM

Author(s): Ying Li, University of Wisconsin-Madison

Computational fluid–structure interaction (FSI) methods are increasingly needed for applications where large deformation, strong multiphysics coupling, and demanding computational scales challenge conventional body-fitted CFD/FSI workflows. This talk presents a rigorous yet practical pathway that combines (i) a continuum-informed lattice solid model derived via energy equivalence with finite elements and (ii) an efficient immersed-boundary coupling to lattice Boltzmann flow solvers, yielding an open and scalable simulation framework for large-scale FSI and for actively actuated soft structures.

First, we introduce an open, portable FSI implementation in which structural dynamics are solved by a lattice model within a particle-based molecular dynamics engine, while the fluid is resolved using a lattice Boltzmann method (LBM) solver and coupled through the immersed boundary method (IBM). This design naturally supports complex moving/deforming geometries without remeshing, enables straightforward parallelization, and provides a unified route to simulate many-body FSI systems. The framework is verified against canonical structural benchmarks and representative FSI cases, and we discuss performance characteristics relevant to large problem sizes.

Second, we extend the same lattice framework to magneto-active soft materials through a formulation for hard-magnetic soft solids. The approach partitions neo-Hookean elasticity into lattice stretching and volumetric contributions, while magnetic actuation is represented as prescribed nodal forces that are computed from the applied field and magnetization configuration. This enables rapid studies of magnetically driven static deformation, dynamic maneuvering, and coupled FSI without intrusive modifications to the underlying solvers. Demonstrations include magnetically actuated beam-like structures, origami-inspired folding, and underwater locomotion of a magnetic soft robot achieved through coupled solid–fluid simulation.

Overall, the OpenFSI–Magttice workflow offers a rigorous, extensible, and HPC-ready route for CFD/FSI simulations with active materials, bridging foundational methodology with practical multiphysics applications.

Speaker



Ying Li

Associate Professor | University of Wisconsin - Madison

ID 332: Modelling Ground-Shock resulting from Free-Air Blast via a Coupled Finite-Volume and Cellular Automata Technique

11:10 AM – 11:30 AM

Author(s): Michael Naranjo, Colorado State University; Hussam Mahmoud, Vanderbilt University

Ground-shock is a phenomenon caused by blast wave interaction with a ground surface. Surface and sub-surface ground shock has been studied extensively for its applications in nuclear test detection, mining, and underground structure design. Air-to-surface ground shock analysis procedures are limited to a small number of studies and explicit computational modelling techniques. Modelling propagation of air-to-ground shock waves aids in evaluating response of underground structures and providing valuable metrics for design. Conventional modelling techniques of air-to-ground shocks require expensive computational multi-material modelling tools such as Finite-Element and Finite-Volume Methods. The proposed method utilizes two different computationally efficient methods, Cellular Automaton (CA) and Finite-Volume (FV) to model wave propagation beginning from above surface detonation to sub-surface ground shock.

The development of a coupled-modelling method for air-to-ground shock propagation creates an efficient method for analysis of underground structures. The coupled approach begins with a robust, multi-material 1D Eulerian solver. Detonation products are modeled using the Jones-Wilkins-Lee equation of state, while the surrounding air is represented with the Ideal Gas Law. The outward wave propagation is captured with a Monotonic Upstream-centered scheme for Conservation Laws (MUSCL) and Harten-Lax-van Leer Contact solver (HLLC). A suitable location for data extraction based on air and equation of state properties allows for outputs from the 1D model to be utilized in single material 2D and 3D models. The 2D and 3D models use inlet boundary conditions defined from the 1D model to capture higher dimensionality in air wave propagation and ground-surface interaction. Solutions are obtained using MUSCL and HLLC schemes in higher dimensionality as well. Ground-surface wave interaction is captured and converted to loading in an elastic CA model to capture ground wave propagation. The CA incorporates a rules-based approach to update discrete velocities and displacements through time and accurately describe material behavior to impulse loads. The FV solver and CA are compared both separately and coupled using published results as well as commercial software such as ANSYS and ABAQUS.

Speaker



Michael Naranjo

Student | Colorado State University

MS 078: Wind, surge-wave, flooding and their impacts on infrastructure systems and coastal land

9:30 AM – 11:30 AM | Location: UMC 247

Chair(s): Chao Sun; Celalettin Ozdemir

Moderators



Chao Sun

Associate Professor | Louisiana State University

ID 127: Estimation of Wind-Induced Dynamic Response of Ground-Mounted Solar Panel Arrays under Lake Superior Wind Conditions

9:30 AM – 9:50 AM

Author(s): Hanshu Zhang, Coastal Carolina University; You-Jia Li, University of California, Berkeley; Matthew DeJong, University of California, Berkeley

Due to the vulnerability of ground-mounted solar panel arrays to gusty winds, experimental testing and simulation of dynamic behavior of solar systems are motivated. This study proposes a novel modeling approach for efficiently estimating the dynamic behavior of a ground-mounted solar panel array model under nonstationary stochastic wind loads. First of all, fiber optic sensing is applied to monitor the wind-induced torsional strains and displacements of solar panel arrays from Michigan Solar Regional Test Center (MI RTC) in Houghton, Michigan, where winds are influenced by Lake Superior. Anemometers next to solar panel arrays are installed to record the mean wind velocities. Next, nonstationary stochastic wind loads on a solar panel array model are generated from nonstationary wind velocities simulated using both the recorded mean wind velocities and the wave-based spectral representation method (SRM) [1, 2], and from the mean pressure coefficients [3, 4] derived from the computational fluid dynamics (CFD). Further, the simulated stochastic wind loads are applied to the solar panel array model in Open System for Earthquake Engineering Simulation (OpenSees) to simulate corresponding dynamic behavior. Displacements of solar panel modules and torsional strains on the torque tube are estimated to observe the performance of the solar panel array. Mode shapes and the corresponding frequencies are also obtained. The simulated results are compared with the field measurement to evaluate the accuracy and reliability of the proposed approach.

[1] Bao, X., Li, C. "Fast simulation of non-stationary wind velocity based on time-frequency interpolation." Journal of Wind Engineering and Industrial Aerodynamics 193 (2019): 103982.

[2] Benowitz, B. A., Deodatis, G. "Simulation of wind velocities on long span structures: A novel stochastic wave based model." Journal of Wind Engineering and Industrial Aerodynamics 147 (2015): 154-163.

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[4] Aly, A. M., Bitsuamlak, G. "Aerodynamic loads on ground-mounted solar panels: multiscale computational and experimental investigations." Advances in Civil, Environmental, and Materials Research (ACEM14), 2014.

Speaker



Zhang Hanshu

Assistant Professor | Coastal Carolina University

ID 199: High-fidelity Modeling of Integrated Aero-Hydro-Structural-Mooring Dynamics of Floating Wind Turbines

9:50 AM – 10:10 AM

Author(s): Chao Sun, Louisiana State University; Pengxu Zou, Louisiana State University

Developing critical technologies for floating offshore wind turbines (FOWTs) is imperative to meet the rapidly increasing demand for clean energy. Compared with fixed-bottom turbines, FOWTs enable access to deep-water regions, offering larger power capacities and reduced visual impact. However, understanding their complex dynamic responses remains challenging due to strong nonlinear aero–hydro–structural–mooring interactions, which require advanced multi-physics modeling, laboratory testing, and field measurements. In this study, a high-fidelity, fully coupled aero–hydro–mooring numerical model for FOWTs is developed using OpenFOAM. An integrated and numerically robust coupling strategy is implemented to consistently resolve the interactions among aerodynamic loads, hydrodynamic wave effects, and mooring system dynamics. To accurately handle the large-amplitude motions of the floating platform under extreme environmental conditions, an overset mesh technique is employed. In addition, simulations using the widely adopted open-source program OpenFAST are conducted for comparison.

A series of numerical case studies are performed under both operational and extreme wind–wave conditions. Under operational conditions, good agreement is observed between the OpenFAST predictions and the high-fidelity CFD results. However, under extreme conditions, noticeable discrepancies arise. The results indicate that strong wind–wave coupling effects significantly influence the dynamic responses of the FOWT system, revealing nonlinear interaction mechanisms that cannot be fully captured by mid-fidelity or uncoupled modeling approaches. These findings demonstrate the capability of high-fidelity CFD-based methods to resolve complex coupled dynamics, which provide valuable insights for the analysis, planning, and design of next-generation floating offshore wind turbines.

Speaker



Chao Sun

Associate Professor | Louisiana State University

ID 261: Application of a Multi-layer Model to Shoaling and Breaking Waves

10:10 AM – 10:30 AM

Author(s): Hunter Boswell, US Army Coastal and Hydraulics Laboratory; Christopher (Ryan) Denney, US Army Coastal and Hydraulics Laboratory; Frank D. Han, Missouri University of Science and Technology; Guirong Yan, Missouri University of Science and Technology; Wouter Mostert, University of Oxford

Breaking waves play a key factor in the design of civil structures and other infrastructure in coastal regions. In numerical simulations, detailed energetics of breaking waves are usually only obtainable by computationally expensive methods such as multi-phase direct numerical simulation (DNS). Multi-layer models present a lower-cost alternative at the potential expense of fidelity. In this study, we present an analysis of breaking wave energetics using a vertically-Lagrangian multi-layer model within the Basilisk framework (Popinet, 2020, J. Comp. Phys., 418: 109609). We study solitary gravity waves which shoal and break on a simple bathymetry consisting of a uniform initial (“offshore”) depth followed by a uniform beach ramp and finally a uniform depth (“inshore”) beach area. The wave initial amplitude, beach slope, and inshore depth are varied, and the dissipation rate is determined for each case and compared to DNS data from prior work. Further, we explore mechanisms which enable the coupling of multi-layer to DNS to inform possible future multi-scale frameworks.

Speaker



Hunter Boswell

US Army Coastal and Hydraulics Laboratory

ID 324: Breaking wave effects on a floating offshore wind turbine with varying pontoon orientations

10:30 AM – 10:50 AM

Author(s): Lucas Baumgartner, University of Colorado Denver; Shengzhe Wang, University of Colorado Denver

The adoption of floating offshore wind turbines (FOWT) is a crucial step towards energy decarbonization. In comparison to traditional turbines, FOWTs have access to higher wind speeds of greater stability. However, they are exposed to harsh marine conditions, like breaking waves, which could result in damage and diminished efficiency. Consequently, FOWTs must be analyzed against extreme hydrodynamic events to assess applicability within variable sea states. Wang and Chuang (2025) previously investigated the effects of breaking wave impingement on a FOWT along a single direction. Expanding on that work, this study introduces newly gathered data on the FOWT as a function of wave directionality using Smoothed Particle Hydrodynamics (SPH). SPH is a Lagrangian numerical method which calculates trajectories of discrete fluid particles within a domain using the discretized Navier-Stokes equations. The method was successfully validated against a physical experiment by replicating a plunging breaker impacting a tension-leg platform structure. The dynamics of the semi-submersible OC5-DeepCwind FOWT with three pontoons arranged in a triangular configuration were subsequently evaluated in response to a 27 m nonbreaking or breaking wave (generated via extreme wave focusing) approaching at 0, 90, and 180 degrees relative to the turbine axis. To facilitate different impingement locations, the turbine tower was placed at 200 m (nonbreaking), 300 m, 320 m, 340 m, 360 m, and 400 m from the wavemaker, with the location of breaking wave impingement maintained at 340 m. The maximum impulsive force between all cases resulted from the 180-degree FOWT at 300 m, with a 97% increase from the nonbreaking case at 200 m and a 12% increase from the 0-degree orientation. In comparison, the 90-degree FOWT had the lowest maximum force which occurred when the tower was located 340 m from the wavemaker, with an 18% decrease relative to the 0-degree orientation. Similarly, the maximum surge and pitch accelerations occurred when the breaking wave impacted the 180-degree FOWT placed at 300 m, followed by the 180-degree FOWT at 340 m. The maximum mooring tension varied with orientation, but the highest tension occurred on lines closest-to-parallel to the wave direction in front of the FOWT. For each mooring line, non-breaking waves resulted in higher mooring tensions than their breaking counterparts. By studying the impacts of breaking waves, wave directionality, and impingement locations on FOWTs, engineers and planners can confidently account for extreme events, like hurricanes, which could damage FOWTs and hinder the future of their development.

Speaker



Lucas Baumgartner

Structural Engineer | Amentum, CU Denver

ID 402: Multiscale Modeling of Backward Erosion Piping Initiation and Evolution in Flood Protection Infrastructure

10:50 AM – 11:10 AM

Author(s): Zhijie Wang, Washington State University; Caglar Oskay, Vanderbilt University; Alessandro Fascetti, University of Central Florida

Backward erosion piping (BEP) is a critical internal erosion mechanism governing the failure of flood protection and water-retaining infrastructure subjected to flooding and hydraulic loading, yet its initiation and evolution remain poorly understood across scales. This contribution presents a unified multiscale, multiphysics framework for modeling BEP initiation and progression under seepage flow, with explicit incorporation of soil variability and time-dependent erosion mechanisms.

At the grain scale, a stochastic initiation model is developed based on the theory of rate processes, linking fundamental particle kinetics under hydraulic forcing to probabilistic descriptions of BEP onset. An initiation probability function is derived to quantify the influence of soil heterogeneity, and an analytical connection between grain-scale kinetics and Weibull statistics is established. This formulation provides a physically grounded explanation for observed variability in critical hydraulic gradients and reconciles mechanistic modeling with phenomenological weakest-link behavior. Building upon this foundation, a validated multiscale probabilistic framework is formulated to predict BEP initiation across several orders of magnitude in scale. Calibration using small-scale experimental data enables accurate prediction of critical hydraulic conditions at larger scales, while capturing grain-size effects and uncertainty bounds relevant to flood protection systems.

To address BEP evolution, a three-dimensional dual random lattice modeling framework is introduced, incorporating a novel rate-process-based constitutive relationship that links seepage energy density to time-dependent soil erosion. A coupled lattice degradation algorithm enables accurate computation of evolving hydraulic gradients and pipe progression under multiphase flow conditions. Model predictions show good agreement with laboratory observations, including erosion front advancement, pipe growth rates, and local gradient evolution.

Collectively, these developments provide a mechanistically informed, probabilistic, and multiscale modeling framework for assessing flooding-induced internal erosion and failure mechanisms in flood protection infrastructure, contributing to improved resilience analysis and hazard mitigation under extreme hydrologic events.

Speaker



Zhijie Wang

Assistant Professor | Washington State University

ID 501: LES-based Quantitative Analysis of Hurricane Boundary-Layer Aerodynamic Loading on a15-MW Floating Wind Turbine

11:10 AM – 11:30 AM

Author(s): Hossein Babaei, Louisiana State University; Chao Sun, Louisiana State University

The aerodynamic response of large floating offshore wind turbines is essentially influenced by the structure of the incoming turbulent wind field. Under extreme tropical cyclones (e.g., major hurricanes), the wind fields become highly turbulent and non-stationary, which complicates the characteristics of aerodynamic loads and responses of floating wind turbines. Nevertheless, current design standards do not explicitly model extreme tropical cyclones and rely on stochastic inflow models developed for neutral atmospheric conditions and rooted in simplified statistical and spectral representations. Such assumptions can introduce structural inconsistencies in the generated flow fields, particularly in their turbulence, spatial coherence, wind shear and veer, that directly influence load predictions for large floating systems. For 15-MW floating wind turbines with large rotor diameters and hub heights, these limitations become increasingly problematic. Characteristics that may be inconsequential for smaller turbines grow significant at larger scales, and the heightened sensitivity of floating platforms to broad, coherent turbulent structures further magnifies these concerns. In this study, we examine how different turbulence-generation methods affect short-term load predictions for a 15-MW semi-submersible turbine operating in severe tropical cyclone conditions. High-resolution large-eddy simulations are conducted to capture the multiscale, highly anisotropic turbulence characteristic of cyclone boundary layers, including strong shear, elevated turbulence kinetic energy, and three-dimensional coherent structures. These simulated inflow fields are then compared with standard stochastic models to assess how discrepancies in hurricane wind field characteristics (turbulence, spatial coherence, wind gust, wind shear and veer, etc.) propagate into platform motions, mooring-line tensions, and tower- and blade-base loading. Results indicate that, under extreme tropical cyclones, conventional stochastic inflow models can significantly misrepresent turbine loading. These discrepancies stem largely from how the models misrepresent spatial coherence and cyclone-scale turbulent structures, leading to notable deviations in predicted responses across wind-speed regimes. These findings underscore the need to reassess inflow modeling practices and design load cases for next-generation offshore wind farms operating in hurricane-prone environments and suggest that turbulence fields explicitly resolving cyclone dynamics may be essential for reliable design-load evaluation of large floating turbines.

Speaker



Hossein Babaei

Mr. | Louisiana State University

MS 090: 10th Mini-Symposium on 4M (Modeling of Multiphysics, Multiscale, Multifunctional) Engineering Materials and Structures

9:30 AM – 11:30 AM | Location: UMC 415-417

Chair(s): Yong-Rak Kim; Huiming Yin; Chung Song; Jianqiang Wei

Moderators



Yong-Rak Kim

Professor | Texas A&M University

ID 42: A chemo-mechanical analysis of the creep behavior of structural adhesives with different curing degrees

9:30 AM – 9:50 AM

Author(s): Yilin Wang, Ghent University; Jan Vorel, Czech Technical University in Prague; Roman Wan-Wendner, Ghent University

Structural adhesives are increasingly more commonly used to connect load-bearing structural elements, especially in retrofitting and strengthening applications. A reliable assessment of the long-term behavior of structural adhesives is indispensable for their application in structural engineering. Understanding the creep behavior of structural adhesives is paramount, as it directly impacts the performance and service life of bonded structures. A substantial amount of experimental data exists on the creep behavior of polymers across various curing degrees. However, previous research efforts that aimed to model creep behavior remained limited to a certain degree of cure, typically the fully cured state. Moreover, it has been shown that the creep behavior in tension and shear can deviate quite substantially from each other. Thus, formulating a creep model that is applicable to a general three-dimensional stress state in various loading scenarios remains an open research question. This study presents a comprehensive numerical analysis of tensile and shear creep tests on a thermoset adhesive, with a particular emphasis on accounting for the degree of cure. Two Kelvin chains are introduced to account for differences between tensile and shear behavior. After calibration on 24-hour tensile and shear creep tests conducted at different curing degrees, a coupled chemo-mechanical multiphysics analysis is executed to investigate post-curing phenomena in incompletely cured bonded structural elements subjected to sustained loads.

Speaker



Yilin Wang

Mr. | Ghent University

ID 92: Multiscale Modeling of Dislocation–Precipitate–PPB Interactions in Powder-Metallurgy Nickel Superalloys

9:50 AM – 10:10 AM

Author(s): Divyesh Mistry, Merrimack College; Avik Mahata, Merrimack College

Nickel-based superalloys derive their exceptional high-temperature strength from complex interactions between lattice dislocations and the ordered γ' precipitate phase. In powder-metallurgy (PM) superalloys, however, Prior Particle Boundaries (PPBs) introduce additional microstructural heterogeneity in the form of inclusion-rich, weakly bonded interfaces that act as preferred sites for dislocation accumulation, strain localization, and early damage initiation. Despite extensive atomistic and continuum-scale studies, a quantitative multiscale framework that links dislocation– γ' interactions to the mesoscale mechanical response of PPB-containing microstructures remains lacking. This work establishes an integrated multiscale modeling framework that couples molecular dynamics (MD) and discrete dislocation dynamics (DDD) to systematically investigate how γ' morphology, size, and volume fraction govern dislocation mobility, strengthening, and strain-hardening behavior, and how these effects interact with heterogeneous PPB networks characteristic of PM-processed superalloys. Building on recent results that quantified dislocation velocities, phonon drag coefficients, two-regime CRSS–volume fraction scaling, and PPB-induced hardening accompanied by persistent internal stress fields, the study consists of three components: (i) MD simulations to construct temperature-dependent dislocation mobility and CRSS databases for multiple γ' morphologies and volume fractions; (ii) DDD simulations incorporating these MD-informed mobility laws to predict collective dislocation behavior, strain hardening, and internal stress evolution; and (iii) development of a PPB– γ' coupling strategy enabling mesoscale predictions of mechanical heterogeneity and residual stress development in PM superalloys.

Speaker



Dr. Divyesh Mistry

Postdoctoral researcher | Merrimack College

ID 108: A coupled thermodynamic–micromechanical framework for predicting the elastic behavior of carbonated cementitious materials

10:10 AM – 10:30 AM

Author(s): Seoyoung Moon, Korea Advanced Institute of Science and Technology; H.K. Lee, Korea Advanced Institute of Science and Technology

Many studies have investigated carbonation mechanisms affecting the mechanical properties of cementitious materials, including strength and elastic modulus [1]. During carbonation, phase transformation from calcium hydroxide to calcium carbonate occurs accompanied by changes in porosity directly influences the mechanical behavior of the materials [1,2]. However, numerical prediction of carbonation remains challenging due to the coupled effects of carbon dioxide concentration, mineral transformation, and porosity evolution [3,4]. Hence, a coupled thermodynamic–micromechanical framework to investigate the elastic behavior of cementitious materials under varying carbon dioxide concentrations proposed by the authors [5] is briefly summarized. In the study, thermodynamic modeling is employed to quantify the mineral transformation and porosity evolution, and the derived microstructural information is incorporated into a micromechanical model to predict the effective elastic properties of the carbonated cementitious materials [5].

Reference

- [1] Chen, T., & Gao, X. (2020). Use of carbonation curing to improve mechanical strength and durability of pervious concrete. *ACS Sustainable Chemistry & Engineering*, 8(9), 3872-3884.
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- [5] Moon, S.Y., Bae, J.H. & Lee, H.K., A thermodynamic–molecular dynamics–micromechanical framework for evaluating the mechanical properties of carbonated CNT-reinforced cementitious materials, in preparation.

Speaker



H.k. Lee

Professor | Korea Advanced Institute of Science and Technology

ID 234: Chemo-Mechanical Phase-Field Fracture Modeling for Cement-Based Materials

10:30 AM – 10:50 AM

Author(s): Yindun Zhao, Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, Texas 77843, United States; Congjie Wei, Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, Texas 77843, United States; Chenglin Wu, Zachry Department of Civil and Environmental Engineering, Texas A&M University, College Station, Texas 77843, United States

Chemical reaction processes in cement-based materials play a crucial role in governing deformation, stress development, and the evolution of fracture. Such processes are inherently coupled with mechanical responses through chemically induced volumetric changes, creating a complex multi-physics coupling scenario. Existing numerical methods often rely on staggered solutions, treating each field separately and risking numerical inconsistencies, which can lead to unrealistic predictions. Hence, there is a pressing need for a fully coupled, unified modeling framework that provides deeper insight into the underlying coupling mechanisms and meets the demand for high-precision solutions.

To provide such a framework for cement-based materials, a 1D surrogate model was constructed to achieve multi-field coupling and predict the chemical and strain evolution, as well as the mechanical properties of the material. In this model, chemical concentration is directly correlated with volumetric strain, which affects the local stress state. The resulting stress field, in turn, alters the material's capacity to accommodate chemically induced deformations, such as the hydration-driven shrinkage. Resolving all these interacting fields simultaneously ensures that each variable evolves consistently under changing conditions, ultimately providing a more accurate and realistic representation of the carbonation process.

To advance this computational framework further, a phase field model was implemented in the finite element approach. This enabled the construction of more versatile 2D models that accommodate multi-field coupling in the presence of cracks. The proposed framework demonstrates efficacy, stability, and generalizability, paving the way for more accurate assessments of fractures in cement-based materials.

Speaker



Yindun Zhao

TEXAS A&M UNIVERSITY

ID 343: Data-Driven Prediction of Mechanical Properties of Graphene Oxide–Reinforced Cementitious Composites

10:50 AM – 11:10 AM

Author(s): Mehdi Ranjkesh Rashteh Roudi, Texas A&M University; Omid Nayeri, University of Pittsburgh; Ramin Shabanpour, University of Pittsburgh; Congrui Jin, Texas A&M University

Graphene oxide (GO) nanosheets have captured researchers' interest due to their large surface area, and remarkable mechanical properties, positioning them as promising nanomaterials for the construction industry. Due to the infinite range of possible mixtures, developing GO-reinforced cementitious nanocomposites often requires extensive experimental work, which is time-consuming and costly. In this study, machine learning is used to predict the properties of GO-reinforced cementitious composites, offering a high level of accuracy to capture complex relationships among material parameters. The input variables includes water-to-cement ratio, GO content, sand-to-cement ratio, surfactant dosage, curing conditions (age and curing temperature), material preparation (sequence of component addition), surfactant type, dispersion technique, and GO sheet size, and the state of the added GO (powder or solution) to predict the compressive and flexural strengths of nanocomposites reinforced with GO. Five tree-based ensemble machine learning models—XGBoost, LightGBM, CatBoost, NGBoost, and Ensemble—were utilized. Four synthetic data generation methods were employed to augment the training dataset: Gaussian Copula, Conditional Tabular Generative Adversarial Network (CT-GAN), Tabular Variational Autoencoder (TVAE), and the Synthetic Minority Over-sampling Technique for Nominal and Continuous features (SMOTE-NC). Five model-interpretation techniques were employed: Gini importance, F-score, permutation importance, Local Interpretable Model-agnostic Explanations (LIME), and Shapley Additive exPlanations (SHAP). These techniques were utilized to interpret the models and to quantify the contribution of individual features to the model outputs. The results demonstrated that CatBoost provides more reliable and accurate results for compressive and flexural characteristics and better maps the relationships between input variables.

Speaker



Mehdi Ranjkesh Rashteh Roudi

Texas A&M University

ID 574: Strength Reduction and Geotechnical/Geological Condition in Nebraska and Midwestern States

11:10 AM – 11:30 AM

Author(s): Chung Song, University of Nebraska-Lincoln; Bashar Al-Nimri, University of Nebraska-Lincoln; Basil Abualshar, NDOT; Dhurba Pandey, UNL-Lincoln; Jongwan Eun, University of Maryland; Seunghee Kim, UNL-Lincoln

The revised CPT was adapted to inject water at targeted depths, inducing controlled moisture infiltration and capturing real-time soil softening over designated intervals of 30, 60, or 90 minutes. Through tip resistance (q_c) and sleeve friction (f_s) measurements under “in situ” and “wet” conditions, the test effectively identified fully disturbed/low strength zones around the sleeve. Simultaneous sampling at test locations facilitated laboratory characterization of soil index properties. Subsequent direct shear testing under field-moisture conditions and 48 hour submerged conditions confirmed that high-plasticity soils exhibited similar strength loss. Conversely, lower-plasticity soils demonstrated limited magnitude of shear strength reductions.

The correlation proposed by Robertson (2009) was employed to estimate undisturbed strength (s_u) and disturbed strength ($s_u(d)$) for the revised CPT parameters, and these correlations were compared to laboratory direct shear strength test data. Marked decreases in peak shear strength similar to FSSS were observed at most sites. These outcomes well aligned with Skempton's (1970) concept of FSSS, validating the measurement scheme developed in this study. Overall, the revised CPT procedure offers a reliable, efficient in situ method to evaluate fully softened shear strength, facilitating improved assessments of slope stability and soil behavior.

Speakers will discuss distribution of these soils, geological history, related troubles, mechanism/magnitude of strength reduction.

Speaker



Chung Song

Professor, University of Nebraska - Lincoln | University of Nebraska

MS 091: Advances in Modeling of Material Damage and Fracture

9:30 AM – 11:30 AM | Location: UMC 382-384-386

Chair(s): Mostafa Mobasher; Lampros Svolos; Aditya Kumar; Georgios Moutsanidis; Alessandro Fascetti; Ravindra Duddu; Haim Waisman

Moderators



Lampros Svolos

Dr. | University of Vermont

ID 78: Microstructure-based simulation for predicting microscale mechanical behavior of cement paste

9:30 AM – 9:50 AM

Author(s): Donghui Eum, Yonsei University; Branko Šavija, TU Delft; Erik Schlangen, TU Delft; Tong-Seok Han, Yonsei University

Cement-based materials are inherently heterogeneous due to their complex microstructure. This microstructure strongly influences their mechanical properties. Therefore, microstructure-based prediction of mechanical behavior at the microscale is crucial for developing a multiscale framework to understand their macroscopic response. In this study, the tensile strength of cement paste was evaluated at two different scales (micro and macro) using experimental measurements and numerical simulations. Cement paste specimens with different water-to-cement (w/c) ratios of 0.4, 0.5, and 0.6 were prepared. At the macroscale, 5 mm cubic specimens were fabricated, and in-situ splitting tests were conducted to evaluate the tensile strength. In addition, nanoindentation tests were performed, and the input parameters were determined by combining microstructural characteristics obtained from micro-CT with mechanical properties obtained from nanoindentation. Microstructure-based splitting simulations were conducted using the phase-field fracture model with the determined parameters [1]. At the microscale, 100 μm cubic specimens were fabricated, and splitting tests were conducted [2]. For each w/c ratio, 50 specimens were tested to reduce uncertainty. The results show that an increase in porosity with increasing w/c ratio leads to a significant reduction in tensile strength. Similar to the macroscale analysis, microstructure-based splitting simulations were performed, and the results showed good agreement with the experimental data. The proposed multiscale analysis framework used in this study was validated against experimental results and was shown to accurately predict the mechanical behavior of cement paste at the microscale. This approach could be used to accelerate the development of cement-based materials and the evaluation of existing materials.

[1] S.-Y. Kim, D. Eum, H. Lee, K. Park, K. Terada, T.-S. Han, Evaluating tensile strength of cement paste using multiscale modeling and in-situ splitting tests with micro-CT, *Constr. Build. Mater.* 411 (2024) 134642.

[2] H. Zhang, B. Šavija, Y. Xu, E. Schlangen, Size effect on splitting strength of hardened cement paste: Experimental and numerical study, *Cem. Concr. Compos.* 94 (2018) 264-276.

Speaker



Tong-Seok Han

Prof. | Yonsei University

ID 81: Interpreting crack healing in brittle solids using a Surface Force-based Fracture Theory (SFFT)

9:50 AM – 10:10 AM

Author(s): Hooman Dadras, Civil Engineering Department, University of Colorado Boulder; Yida Zhang, Civil Engineering Department, University of Colorado Boulder

Spontaneous Crack Healing (SCH) has been observed in several brittle materials such as glass and mica. The energy release rate for the onset of SCH and subsequent re-cracking (RC) typically occur at a threshold value lower than that compared to initial cracking, indicating a hysteresis in the crack velocity vs. relationship. Despite its practical implications for fatigue-limit predictions, this behavior has not been systematically incorporated into fracture mechanics frameworks, even though Rice [1978]'s foundational work on fracture thermodynamics alluded to such phenomena. In this study, we expanded the recently developed Surface-Force-Based Fracture Theory (SFFT) [Eskandari-Ghadi et al., 2022; Dadras et al., 2025] to model the hysteretic behavior of subcritical crack growth (SCH), healing, and re-propagation in brittle solids. Two major improvements were made: 1) the transport solver was enhanced to account for the coupling between the crack profile and the diffusivity of fluid species, ensuring accurate resolution of concentration profiles during crack growth and healing; and 2) a Lagrangian-multiplier contact formulation was implemented to prevent crack surfaces from overlapping or interpenetrating, a critical advancement for enabling the SFFT to handle crack unloading and healing. The model is validated against SCG-SCH-RC data on mica at different relative humidity levels. New insights are gained on the potential microphysics that govern the kinetics of SCG-SCH in these systems.

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Dadras, H., M. Eskandari-Ghadi, S. Nakagawa, B. Gilbert, and Y. Zhang (2025), Complex dependence of calcite crack kinetics on salinity: The role of DLVO and hydration forces, *Journal of Geophysical Research: Solid Earth*, 130(9), e2025JB031332.

Speaker



Hooman Dadras

Graduate Research Assistant | University of Colorado Boulder

ID 455: One-dimensional analysis of failure and localization with a data driven approach

10:10 AM – 10:30 AM

Author(s): Gilles Pijaudier-Cabot, Universite de Pau et des Pays de l'Adour; Julien Khoury, Universite de Pau et des Pays de l'Adour

In recent years, data-driven approaches have begun to replace traditional constitutive models. This change comes from two main factors: the increasing complexity of traditional, physics-based, constitutive models, and the growing amount of experimental data now available.

Strain softening in quasi-brittle materials is an archetypal example of difficulties encountered with traditional models. They cannot handle strain localization due to softening properly and the well-known remedy is enrichment. Such an enrichment (or nonlocality) is intended to capture interactions emerging from the microscale upon localization, but in a rather arbitrary way, without a clear-cut idea of its physical meaning. Micro- or meso-scale models embed such interactions because they introduce an explicit description of the structure of the material at a lower scale, that of heterogeneities. They can provide a high-fidelity description of the material response with true predictive capabilities, but still without elucidating how and with which variables macro-scale constitutive model should be written.

With the development of advanced experimental techniques, the amount of experimental data available for constitutive modeling has increased drastically. Machine learning approaches offer an alternative to traditional modeling. Such an approach does not rely on explicit constitutive equations, which may be a difficulty when it comes to interpreting the physical meaning of the main variables that govern the material response. A mid-point approach, introduced originally by Ortiz and co-workers keeps the general framework of analytical modelling while relying on experimental data. The material behavior is no longer represented through explicit constitutive equations, but rather by a discrete cloud of data.

In this study, we apply this data-driven scheme to the modelling of failure of a quasi-brittle material such as concrete. Synthetic data sets, generated from a bi-linear damage model or with a lattice discrete particle model, are used. For the sake of simplicity, we consider a one-dimensional problem. As expected, solutions are sensitive to the finite element discretization. A localization limiter is needed, and the implementation of a non-local (integral) model circumvents the difficulty. There is, however, a notable observation in this case: optimal sets of strain, stress, and non-local history variable lie consistently outside the data set and do not converge within the data set upon mesh refinement. The reason is that data set should not be local but encompass all possible nonlocal interactions involved during failure. The Lip-field approach offers a convenient technique to preserve locality of the constitutive response and it is found to be very easy to implement.

Speaker



Gilles Pijaudier-Cabot

Université De Pau Et Des Pays De L'adour

ID 224: Experimental and Numerical Investigation of Stress-Driven Interaction Between Hydraulic and Natural Fractures

10:30 AM – 10:50 AM

Author(s): Maithah Alaleeli, New York University Abu Dhabi; Shivesh Shandilaya, The University of Utah; Mostafa Mobasher, New York University Abu Dhabi; Shahrzad Roshankhah, The University of Utah

Predicting fracture initiation and propagation in materials containing pre-existing discontinuities remains a fundamental challenge in damage and fracture mechanics, particularly when evolving local stresses govern crack trajectory. Most existing fracture interaction criteria rely on far-field stress measures or geometric considerations and therefore do not account for local stress redistribution, shear-induced stress rotation, or mixed-mode loading near discontinuities.

In this work, we combine controlled laboratory experiments with full-field digital image correlation and coupled hydro-mechanical numerical simulations to directly resolve deformation, stress evolution, and fracture propagation in specimens containing inclined discontinuities. The mechanisms we investigate are relevant to brittle poroelastic materials encountered in subsurface settings, including hydraulic fracturing, geothermal stimulation, and geological storage. To reproduce rock-like fracture behavior while enabling direct observation of crack trajectories, we conduct experiments on transparent PMMA specimens containing planar, non-cemented frictional discontinuities that are allowed to slip under compressive loading. Guided by these experiments, we model fracture propagation numerically using the extended finite element method, which enables discontinuous crack growth without prescribing the fracture path. Mixed-mode fracture behavior is captured using the energy-based Benzeggagh–Kenane criterion, permitting coupled mode-I and mode-II dissipation. Full-field experimental measurements of displacement, strain, fracture trajectories, and fluid pressure histories were used to directly initialize, calibrate, and validate the numerical simulations, achieving qualitative, quantitative, and trend-based agreement.

We find that fracture trajectories are governed by the evolution and polarity of local shear stresses and strains, which redistribute the near-tip stress field and drive fracture curvature toward or away from pre-existing discontinuities. Additionally, we find that pure Mode-I formulations are unable to reproduce the observed fracture trajectories once shear-induced stress redistribution dominates near discontinuities, whereas mixed-mode fracture models capture the observed transitions from tensile-dominated to shear-assisted propagation. By linking shear-induced stress redistribution to fracture attraction or repulsion, our results provide a basis for predicting fracture connectivity in subsurface systems, informing decisions on whether fracture growth will enhance reservoir stimulation (e.g., for enhance-oil recovery or geothermal applications) or compromise containment in storage scenarios (e.g. CO₂ or H₂ sequestration).

Speaker



Maithah Alaleeli

Postdoctoral Associate | New York University

ID 225: Resolving pathological damage widening in gradient-enhanced models

10:50 AM – 11:10 AM

Author(s): Roshan Philip Saji, New York University Abu Dhabi; Panos Pantidis, New York University Abu Dhabi; Mostafa Mobasher, New York University Abu Dhabi

We present a modified non-local gradient damage (MNLD) model that addresses the pathological damage widening phenomenon observed in gradient-enhanced continuum damage models. Our study addresses the challenges of conventional gradient damage formulations by modifying both the stress degradation function and the forcing term in the Helmholtz free energy expression. Additionally, we adopt a modified exponential damage evolution law that ensures damage evolves to its maximum value within an appropriate strain range. With these changes, the thermodynamic damage driving force vanishes and evolution of the forcing term progressively diminishes as damage reaches its terminal value. As a result, the damage localization zone maintains a constant fixed-width during its evolution, rather than spreading spuriously into the surrounding material. The development of the MNLD model is informed by two intermediate formulations, each targeting one of these modifications independently before being combined into a unified formulation. This systematic approach allows for a clear understanding of the influence of each modification. The numerical validation of the MNLD model is conducted through a series of 1D, 2D and 3D benchmark simulations, which demonstrate its ability to consistently yield fixed-width damage bands. The results of our analysis, verified across different geometries and loading conditions, demonstrate that MNLD demonstrates mesh independence. Also, we present the influence of control parameters on the performance of MNLD along with recommendations for optimal implementation. Importantly, the MNLD model can be easily incorporated into existing finite element implementations of gradient damage models with only minor modifications. Overall, our findings demonstrate a practical and rigorous resolution to the long-standing issue of artificial damage band broadening in gradient-enhanced damage approaches, offering an effective and practical solution for engineering applications.

Speaker



Roshan Philip Saji

Dr. | New York University Abu Dhabi

ID 294: Characterization and constitutive modeling of CNT-PLA piezoresistive materials

11:10 AM – 11:30 AM

Author(s): Habiba Eldababy, Mechanical Engineering Department, Tandon School of Engineering, New York University, USA; Panos Pantidis, Civil and Urban Engineering Department, New York University Abu Dhabi, UAE; Georgios Tzortzinis, Institute of Lightweight Engineering and Polymer Technology, Dresden University of Technology, Germany; Mostafa Mobasher, Civil and Urban Engineering Department, New York University Abu Dhabi, UAE

This research presents an effort towards understanding the multiphysical properties of carbon-nanotube doped polylactic acid (CNT-PLA) piezoresistive composites. The effort spans the mechanical and piezoresistive experimental characterization, as well as the development of appropriate constitutive modeling to capture the material response. The range of the response considered includes the nonlinear directional mechanical behavior and the coupled electromechanical response; which is relevant to multifunctional structural applications. Printing-induced anisotropy and nonlinear material response play a dominant role in the mechanical and sensing performance of architected lattice systems, motivating the development of robust numerical models that bridge material-scale behavior and lattice-scale response. At the material level, a finite element-based constitutive framework is developed to represent the anisotropic, tension-compression asymmetric response of a CNT-PLA filament. Model parameters are identified through an optimization-based calibration procedure that enables consistent representation of material behavior across multiple loading modes and orientations. The piezoresistive response is modeled with a coupled electromechanical description, with orientation-dependent conductivity and a strain-based resistivity formulation. This enables the numerical prediction of resistance changes induced by mechanical deformation, providing a unified model for simulating both structural response and sensing functionality. The proposed model is subsequently validated with a lattice-scale simulation. Overall, the proposed framework offers a robust numerical foundation for modeling multifunctional architected systems governed by nonlinear material behavior and coupled sensing mechanisms. This work lays the foundation for predictive design and optimization of multifunctional architected materials using physics-informed, high-fidelity numerical models.

Speaker



Habiba Eldababy

Graduate Research Assistant | Computational Solid Mechanics Lab

MS 100: Computational Geomechanics

9:30 AM – 11:30 AM | Location: HUMN 1B80

Chair(s): Hyoung Suk Suh; Shabnam Semnani; Jinhyun Choo; WaiChing Sun; Craig Foster; Richard Regueiro; Ronaldo Borja

Moderators



Hyoung Suk Suh

Assistant Professor | Case Western Reserve University

ID 937: Physics-integrated machine learning for landslide risk assessment

9:30 AM – 9:50 AM

Author(s): Shabnam Semnani, UC San Diego

Landslides are devastating natural disasters that occur frequently around the world, resulting in significant economic losses and casualties. Statistics show that the most frequent and widespread damaging type of landslides are triggered by precipitation. Machine learning techniques have been applied to predict landslides based on past events. However, there are a number of challenges associated with these techniques, including the selection of input features, the intrinsic class imbalance caused by the rare occurrence of landslide events, and the extrapolation capability of the machine learning algorithm for climate change studies. Data-driven methods can be insufficient for extrapolation and uncertainty could be introduced due to the selection of landslide conditioning factors along with the completeness or quality of the landslide inventory. To address these challenges, we propose an enhanced physics-informed data-driven machine learning modeling strategy for landslide hazard assessment and use it for landslide risk assessment. The proposed physics informed machine learning framework outperforms the data-driven model in terms of general prediction capability, data efficiency, and extrapolation capability. Averaged landslide susceptibility maps of California are generated based on the developed models, and the physics informed models are shown to align better with the historical observations compared with the data-driven model.

Speaker



Yi Han

Graduate Student Researcher | University of California San Diego

ID 131: A diffuse interface approach for non-isothermal Stokes-Darcy flow with immersed transmissibility conditions in heterogeneous porous media

9:50 AM – 10:10 AM

Author(s): Hyoung Suk Suh, Case Western Reserve University

Understanding and accurately modeling the interplay between free-flowing fluids and porous media is essential for a wide array of scientific and engineering applications, particularly under non-isothermal conditions. In this work, we introduce a unified computational framework that leverages a diffuse interface approach to simulate coupled Stokes-Darcy flows with heat and mass transfer, circumventing the need for conventional domain decomposition and explicit interface tracking. By employing an Allen-Cahn type phase field model, we represent the interface between free and porous regions as a smooth transition zone, enabling the direct incorporation of transmissibility conditions as immersed boundary constraints. This allows simultaneous enforcement of mass, momentum, and energy continuity, even in transient, thermally driven scenarios. The framework supports operator splitting for isothermal processes, facilitating efficient numerical solution without sacrificing accuracy. Through a series of numerical experiments, including benchmark verification, characterization of vuggy porous materials, fractured media, and geothermal heat exchangers, we demonstrate the model's versatility and capacity to capture complex hydrothermal interactions. The results highlight the influence of interface properties, such as slip velocity and thermal conductance, on system behavior and provide insights into optimizing energy systems and subsurface processes. This study lays the groundwork for robust, extensible simulation tools that advance the modeling of multi-physics phenomena in heterogeneous domains.

Speaker



Hyoung Suk Suh

Assistant Professor | Case Western Reserve University

ID 204: Multi-scale DEM Modeling of Aggregate Crushing

10:10 AM – 10:30 AM

Author(s): Tannaz Karimi Soumehsaraei, Cornell University; Flynn Basehart, Cornell University; Aryong Yun, Georgia Tech; Sheng Dai, Georgia Tech; Chloe Arson, Cornell University

Polymineralic aggregate crushing plays a fundamental role in mining and materials manufacturing processes; however, the influence of mineralogical heterogeneity and grain morphology on crushing behavior remains insufficiently understood. To address this gap, this study presents an integrated multi-scale framework that combines laboratory experiments, discrete element modeling (DEM), and image processing to investigate the crushing behavior of polymineralic granite aggregates.

Single-particle crushing tests are simulated using the open-source DEM software LIGGGHTS, with numerical models calibrated against experimental measurements. Intra-mineral mechanical properties are characterized through nanoindentation tests performed with a spherical indenter, yielding elastic modulus and hardness values for individual mineral phases. The experimental nanoindentation load–depth responses are reproduced numerically, and particle and bond micromechanical parameters are systematically calibrated for each mineral species.

Mineralogical information is obtained from XRF–AMICS measurements conducted on one of the surfaces of a cubic granite specimen. The resulting phase-resolved mineralogical map is spatially extrapolated across optical images of all six faces of the sample to reconstruct the mineral distribution over the entire surface using the assumed ground-truth data to calibrate RGB-based segmentation. The segmented faces are then employed as boundary constraints in MCRpy to reconstruct a realistic three-dimensional microstructure of the granite.

To enable DEM simulations, each voxel of the reconstructed microstructure is replaced with a single face-centered cubic (FCC) unit cell, resulting in a cluster-based particle representation of the aggregate. In this discretization, particles inherit mineral labels based on their spatial location within the voxelized microstructure, and micromechanical particle and bond properties derived from mineral-specific nanoindentation calibration are assigned accordingly, preserving detailed mineralogical heterogeneity. Micromechanical properties calibrated from the nano-indentation tests are subsequently upscaled within a DEM-based framework to enable consistent modeling of polymineralic particle clusters at the aggregate scale.

The aggregate-scale response is validated by comparing simulated crushing behavior with experimental stress–strain curves obtained from uniaxial compression tests on granite specimens, allowing further calibration of inter-mineral bond stiffness and strength. The deformation field and crack patterns are additionally compared with experimental observations from digital image correlation (DIC).

Lastly, sensitivity analyses are conducted to elucidate the roles of mineral properties, and grain morphology, in aggregate crushing, enabling estimation of crushing energy requirements and informing optimized fragmentation loading paths.

Speaker



Tannaz Karimi

Ph.D. student | Cornell University

ID 222: Physics–AI Metamodels for Geometry-Aware Computational Mechanics

10:30 AM – 10:50 AM

Author(s): Jiaji Wang, The University of Hong Kong; Chawit Kaewnuratchadasorn, The University of Hong Kong

Computational geomechanics increasingly demands high-resolution simulation over complex geometries, strong heterogeneity, and nonlinear behaviour. However, the computational cost of conventional numerical solvers can be prohibitive in inverse analysis and uncertainty quantification workflows that require large ensembles of forward simulations. Recently, deep-learning methods have gained attention in geomechanics by enabling data-driven approximation, differentiable modelling, and discretisation-agnostic surrogate construction; yet purely data-driven models often suffer from violations of governing physics and limited interpretability. To address these limitations, this work presents physics-integrated neural operator frameworks that serve as geometry-aware metamodels for both quasi-static and time-dependent geomechanics-relevant problems. First, we introduce a Geometry Physics-Informed Neural Operator (GPO) for large-scale solid mechanics, combining geometry encoding, exact Dirichlet boundary enforcement, and an energy loss function that enables training without paired labelled solutions; across 2D–3D elasticity benchmarks spanning 10000 – 10 million DOFs, GPO achieves 3x to 40x speedups over standard FEM while maintaining accurate displacement and stress predictions. Second, we propose a Transformer–Fourier Neural Operator (TFNO) for predicting transient responses under moving-load excitation, which integrates Fourier operator layers with Transformer attention to capture long-range spatial interactions and time-history dependencies, thereby enabling real-time inference and efficient transfer to new topologies. Collectively, these frameworks provide a practical pathway to physics-consistent, geometry-generalizable surrogates that complement established computational geomechanics workflows and accelerate large-scale simulation, parametric studies, and data-driven calibration.

Speaker



Jiaji Wang

HKU

ID 280: I-FENN: An Integrated Finite Element Neural Network Framework with DeepONets for Large-Scale Coupled Multiphysics Simulations

10:50 AM – 11:10 AM

Author(s): Fouad Amin, New York University Abu Dhabi; Diab Abueidda, New York University Abu Dhabi; Panos Pantidis, New York University Abu Dhabi; Mostafa Mobasher, New York University Abu Dhabi

High-dimensional, large-scale coupled multiphysics simulations often require significant computational resources due to the large domain size and the complexity of the interacting physical fields. This work presents a novel framework that combines a Deep Operator Network (DeepONet) with the Finite Element Method (FEM) for thermoelasticity and poroelasticity problems. A hybrid staggered solver is proposed using the Integrated Finite Element Neural Network (I-FENN) strategy. In this approach, the FEM computes the mechanical displacement field. Meanwhile, the neural network predicts the coupled field, such as temperature or fluid pressure. This approach reduces the number of FEM unknowns, lowering the overall computational cost while maintaining high accuracy by achieving equilibrium of the mechanical field every time increment.

The framework is implemented within the open-source FEM solvers deal.II and GOESX, enabling high-performance computing and parallel processing capabilities. The work explores new I-FENN/DeepONet architectures that leverage the generalizability of DeepONet to handle various combinations of natural boundary conditions and body loads. A modified MIONET design is adopted to handle multiple inputs. In addition, a new approach to enforce complex essential boundary conditions is proposed. The implementation investigates the use of a GRU to capture temporal dependencies in loading histories. Additionally, it incorporates group normalization to enhance the stability of the framework's predictions. We explore both data-driven and physics-informed approaches in the DeepONet training.

Examples on thermoelasticity and poroelasticity are included, validating the framework's accuracy, computational efficiency, scalability, and generalization capabilities. Additionally, we explore the numerical stability of poromechanics problems, particularly addressing the occurrence of spurious oscillations in numerical simulations. The results, for previously unseen loading conditions, show that computational savings increase with model complexity while maintaining over 95% accuracy in non-trivial regions. Furthermore, a comparison of I-FENN results with those of a fully surrogate model demonstrates the superior accuracy of the I-FENN framework, along with reduced training requirements and cost. Finally, the study is enriched with comprehensive parametric studies on model training, exploring different learning rates, loss functions, network complexity, and dataset size.

Speaker



Fouad Amin

PhD candidate | New York University

ID 316: Hybrid staggered SNS-FEM framework for axisymmetric multi-physics analysis of elastoplastic porous media

11:10 AM – 11:30 AM

Author(s): Xiaoran Sheng, University of Macau; Qi ZHANG, University of Macau

Thermo-hydro-mechanical (THM) coupling in porous media is ubiquitous in many engineering applications, and numerical modeling provides an efficient way to "visualize" the entire evolution process. In this work, we present a novel staggered multi-physics SNS-FEM framework. Compared with previous publications, several distinctive new features are presented here. (1) We present a different but more concise way to derive the governing energy conservation equations, followed by a novel scaling analysis, from which a new dimensionless constant is provided that controls either one-way or two-way coupling between the hydro-mechanical process and the thermal process. (2) The stabilized node-based smoothed finite element method (SNS-FEM) is extended to the axisymmetric analysis, in which the smoothed strain-displacement matrix and its smoothed gradient are properly defined, even when the domain boundary coincides with the axis of symmetry (\$z\$-axis). (3) The contact heat transfer is properly defined under the dual-mortar contact discretization framework. (4) A new hybrid scheme is proposed, which solves the system equations in a staggered way rather than in a monolithic way, while the accuracy could still be maintained. (5) The developed framework has been applied to more complex scenarios, including more advanced soil constitutive models and finite strain consolidation. In terms of constitutive updating, SNS-FEM is more efficient than the standard FEM due to fewer integration points. All the presented numerical examples are either new or interpreted from a totally new perspective. Finally, the application examples reveal the thermal effects and key differences among the Modified Cam-Clay model, the 1D Elastic Viscoplastic (EVP) model without creep, and the Drucker-Prager model through consolidation and non-isothermal CPT simulations. Overall, this study offers a promising contribution to the understanding and modeling of complex multi-physics problems.

Speaker



Qi ZHANG

Assistant Professor | University of Macau

MS 094: Mechanics and Physics of Granular Materials

9:30 AM – 11:30 AM | Location: VAC 1B20

Chair(s): Ryan Hurley; Marcial Gonzalez; Yimin Lu; Dawa Seo; Alessandro Rotta Loria; Ali Daouadjji

Moderators



Yimin Lu

Assistant Professor | Texas Tech University

ID 27: Effect of load–unload–reload cycles on the shear resistance of railroad ballast in triaxial monotonic tests

9:30 AM – 9:50 AM

Author(s): Shihao Huang, Tarleton State University; Yu Qian, University of South Carolina

Railroad ballast, composed of unbound coarse aggregates, is subjected to repeated vertical load–unload–reload (LUR) actions due to passing trains, which leads to significant particle rearrangement within the track bed. Shear resistance is a critical property governing the stability of ballast, yet conventional investigations predominantly rely on monotonic triaxial tests that do not adequately capture the effects of LUR-induced particle rearrangement. This study examines ballast shear behavior through novel large-scale triaxial tests incorporating axial LUR loading schemes, distinct from traditional cyclic loading, to replicate the mechanical effects of repeated train loads. Experimental results reveal that shear strength is strongly influenced by LUR loading paths: Increased LUR cycles enhance shear resistance due to the development of fabric anisotropy driven by particle rearrangement. Under identical confining pressures and initial densities, monotonic triaxial tests without LUR loading may underestimate ballast shear strength by up to 72.7%. This is attributed to the suppression of particle rearrangement under higher confinement. Furthermore, the shear failure envelope evolves with increasing LUR cycles, rendering failure criteria derived from monotonic tests inadequate for LUR conditions. These findings highlight the limitations of conventional triaxial approaches and underscore the necessity of accounting for particle rearrangement when evaluating the shear strength and failure behavior of railroad ballast and similar granular materials.

Speaker



Shihao (Max) Huang

Assistant Professor | Tarleton State University

ID 146: Measuring the feedback between contact area evolution and stiffness nonlinearity in granular solids

9:50 AM – 10:10 AM

Author(s): Shubjot Singh, Purdue University Fort Wayne; Oluwaseyi Balogun, Northwestern University; Giuseppe Buscarnera, Northwestern University

Granular materials exhibit a pronounced increase in stiffness when subjected to compression, yet the relative roles of particle rearrangement and contact-level deformation in driving this response remain difficult to separate experimentally. To clarify these mechanisms, this work employs a hybrid experimental platform that captures both multi-directional wave propagation and the evolving internal structure of a granular assembly. Axial P-wave velocities were monitored using piezoelectric transducers embedded within the loading pistons, while lateral velocities were measured through a pulsed laser–based ultrasonic method that allows fully non-contact sensing of in-situ packings. Complementary X-ray computed tomography imaging provides grain-scale information on geometric organization and contact evolution during loading.

The results reveal two distinct phases of mechanical adaptation. At lower confinement, changes in wave velocity coincide with particle rearrangement and the establishment of new contacts. As loading increases, the material transitions into a structurally locked state in which continued stiffening occurs primarily through the enlargement of existing contact areas rather than further reorganization. Tomographic analysis shows that contacts oriented along the loading axis experience the greatest increase in area, yielding direction-dependent stiffness and corresponding anisotropy in wave speeds. When interpreted through the lens of Effective Medium Theory and Hertzian contact mechanics, the experimental data display power-law trends that link contact-scale deformation with macroscopic elastic response. Together, these results establish an experimental foundation for linking grain-scale contact mechanics with anisotropic wave propagations, offering new tools for the non-destructive evaluation of geomaterials and stress-dependent metamaterials.

Speaker



Shubjot Singh

Assistant Professor | Purdue University Fort Wayne

ID 266: Graph Neural Network Forecast of Density Relaxation

10:10 AM – 10:30 AM

Author(s): Vishagan Ratnaswamy, IQLAND Innovations; Anthony Rosato, NJIT

The discrete nature of granular materials lends itself to the development of surrogate models that can be generated via structure-specific graph neural networks (GNN's). In this presentation, we report on a graph neural network (GNN) created from a training set consisting of ensembles of particle positions generated via a granular dynamics simulations modeling vibration-induced density relaxation of inelastic, frictional monodisperse spheres. Loose random, poured assemblies subjected 15,000 sinusoidal taps evolve towards increasing bulk solids fraction commensurate with cooperative rearrangements of particles having crystal-like ordering. Each graph is endowed with node-level structural features, such as coordination number and particle positions, as well as bulk properties (i.e., fabric tensor, network topology). A neural relational inference model (= GNN + variational autoencoder and decoder) is then used to generate forecasted graphs, from which various distributions are computed (i.e., solids fraction, coordination number, etc.). Validation is done via comparisons of computed properties with the simulation output. Despite the non-uniqueness of the graphs, strong agreement of these properties with those from the actual data was found.

Speaker



Anthony Rosato

Professor | New Jersey Institute of Technology

ID 351: Origin, General Definition, and Implications of Cryosuction in Frozen Soil

10:30 AM – 10:50 AM

Author(s): Lingyun Gou, University of Wisconsin - Madison; William Likos, University of Wisconsin - Madison; Ziyi Wang, Colorado School of Mines; Ning Lu, Colorado School of Mines

Unfrozen water in frozen soils can migrate from warmer to colder regions driven by a force commonly referred to as cryosuction. Existing explanations of cryosuction based on capillary or premelting theories generally assume a spatially uniform negative pore water pressure within the unfrozen water film. This assumption contradicts experimental observations of increased viscosity and density in adsorptive unfrozen water. Phase equilibrium at the ice-water interface is considered in this study to reveal the thermodynamic origin of cryosuction by incorporating a spatially varying pore water pressure distribution including positive pore water pressure due to adsorption. Cryosuction is formulated as the net pressure difference attributable to both capillary and adsorptive unfrozen water through a unified formulation that remains consistent with the intrinsic spatial variability of adsorptive water properties. The formulation is validated using macroscopic soil column experiments and microscopic film flow experiments. Quantitative comparisons with other potential fluid migration mechanisms in frozen soil demonstrate that cryosuction is the dominant driving force governing unfrozen water migration in Arctic permafrost environments. The formulation advances conceptual and quantitative understanding of cryosuction and provides a unified framework for predicting frost heave phenomena in frozen soil systems.

Speaker



Lingyun Gou

PhD Student | University of Wisconsin - Madison

ID 374: Mesoscale studies on weak shock granular compaction: the role of friction and explicit grain fracture

10:50 AM – 11:10 AM

Author(s): Samuel Lamont, Los Alamos National Laboratory; Nitin Daphalapurkar, Los Alamos National Lab

Granular materials are ubiquitous in natural and engineered systems and often subjected to dynamic and high-impact loading conditions. Under shock and rapid compression, their response is governed by highly localized interactions at the grain scale. In the weak shock regime in particular -- where the system is rapidly compacted but not necessarily crushed at the grain-level -- the emergent response is highly sensitive to interactions at the mesoscale. Simulations that resolve geometry at the level of the individual grain are, thus, essential for understanding the role and evolution of grain morphology and inter-granular interactions on the mechanical behavior of the granular system. With this said, resolving grain-level geometry in a dynamic simulation is computationally expensive, and there are limited studies on granular compaction with simulations that incorporate dissipative processes such as friction and grain fracture. As a result, key questions remain regarding how inter-granular friction regulates force transmission and localization, how grain fracture contributes to densification and wave propagation, and how these mechanisms interact to control compaction wave structure and energy dissipation under weak shocks.

We here employ grain-resolving simulations at the mesoscale to uncover the role of friction and explicit grain fracture during weak shock compaction of granular salt and sugar. Simulations are run using the hydrodynamics code FLAG developed at Los Alamos National Laboratory. Friction is handled using a newly developed algorithm for computing contact normals and tangential motion, which is valid in both 2D and 3D and supports multi-body contact. Explicit grain fracture is modeled using a cohesive traction law, which supports fully separated bodies after a critical traction criterion is met. Each of these physical mechanisms dissipate mechanical energy and affect the densification and propagation of mechanical waves. We provide comparative illustrations of the evolution of thermodynamic properties (energy, pressure, density) and wave substructures in systems with and without inter-granular friction and grain fracture. We compare the results of our simulations with experimental studies on granular compaction where relevant.

Speaker



Samuel Lamont

Scientist | Los Alamos National Laboratory

ID 377: Graph Neural Network Prediction of Interparticle Forces in Granular Media

11:10 AM – 11:30 AM

Author(s): Mobina Taghaddosi, Arizona State University; Nariman Mahabadi, Arizona State University

Granular materials such as soils derive their macroscopic mechanical behavior from particle-scale interactions and the emergence of heterogeneous force-chain networks. Load bearing, deformation, and failure in these systems are governed by the distribution and evolution of interparticle forces rather than by average stress alone. However, these forces are not directly observable in most three-dimensional experiments, and their high-dimensional, history-dependent nature makes them difficult to model using continuum or constitutive approaches. This creates a fundamental gap between particle-scale granular physics and predictive models of macroscopic response under loading.

Discrete element method (DEM) simulations can resolve interparticle forces and force-chain evolution in detail, but they require large-scale computations involving thousands to millions of particles and are often prohibitively expensive for repeated or time-critical analyses. As a result, there is currently no efficient framework that can infer interparticle force networks directly from minimal system information, such as particle positions and boundary conditions, without resorting to full particle-scale simulations.

To address this challenge, we develop an AI-driven modeling framework for granular physics that predicts interparticle forces in three-dimensional granular systems under uniaxial compression using graph neural networks (GNNs). Trained on DEM-generated data, the GNN learns the relationship between particle geometry, contact topology, and boundary conditions and the resulting force transmission. The model accurately predicts both normal and tangential components of contact forces across thousands of particles and successfully reproduces the structure and evolution of force chains.

We evaluate the framework across a wide range of conditions, including varying strain increments, particle counts, particle size distributions, material properties, friction coefficients, loading rates, and damping parameters. The results demonstrate strong generalization and show that interparticle forces can be inferred rapidly from limited input information. This work establishes a scalable, data-driven pathway for linking granular microstructure to macroscopic mechanical response and provides a foundation for real-time predictive tools and digital-twin models for granular materials.

Speaker



Mobina Taghaddosi

Graduate Research Associate | Arizona State University

Lunch Break

11:30 AM – 1:00 PM

Lunch tent #1

11:30 AM – 1:00 PM

Lunch tent #2

11:30 AM – 1:00 PM

Objective Resilience student competition

11:30 AM – 1:00 PM | Location: UMC 247

Probabilistic Methods Student Competition

11:30 AM – 1:00 PM | Location: UMC 382-384-386

Properties of Materials committee meeting and student competition

11:30 AM – 1:00 PM | Location: UMC 425

Education committee meeting

11:45 AM – 12:45 PM | Location: HUMN 125

Poromechanics student competition

11:45 AM – 12:45 PM | Location: CLUB 4-5

Machine Learning student competition

11:45 AM – 12:45 PM | Location: HUMN 135

Computational Mechanics student competition

11:45 AM – 12:45 PM | Location: VAC 1B20

Modeling Inelasticity & Multiscale Behavior student competition

11:45 AM – 12:45 PM | Location: HUMN 1B80

Structural Stability student competition

11:45 AM – 12:45 PM | Location: HUMN 1B90

Dynamics student competition

12:00 PM – 1:00 PM | Location: UMC 415-417

Keynote: Why Fracture Geometry is Important

1:00 PM – 2:00 PM | Location: UMC - Glenn Miller Ballroom

Why Fracture Geometry is Important

Laura J. Pyrak-Nolte, Ph.D.

Distinguished Professor of Physics and Astronomy

Purdue University

Abstract: We may think of rock as “solid”, but all rocks have mechanical discontinuities, generally referred to as fractures. These range in length scale from micro-cracks (μm - mm) to fractures (cm – m) to faults (m – km) and are easily affected by natural and engineered processes, causing them to open, close, initiate, coalesce and/or propagate. Furthermore, natural and engineered fluids can cause geochemical alterations that lead to crack growth or sealing through mineralization. All these changes affect the movement of fluids through fractures. Fractures can be beneficial, for example, to geothermal energy production where fluids are injected and withdrawn from subsurface rocks to extract heat. On the other hand, fractures are detrimental to subsurface sites used for storing fluids (H_2 , CO_2) because they act as well-connected “fast” paths for fluids to leak. Thus, the detection and characterization of fractures is crucial for sustained production/isolation of fluid throughout the life-cycle of a subsurface site.

Over the last three decades, steady progress by the community has led to a deeper understanding of the hydraulic, mechanical, and seismic responses of fractures. A key finding of these efforts is the role of fracture geometry in controlling and linking these responses. In this presentation, I will highlight the importance of fracture geometry in understanding the behavior of fractures and fracture networks.

Acknowledgment: This work was supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, Geosciences Research Program under Award Number (DE-SC0001048).

Biosketch: Laura J. Pyrak-Nolte is a Distinguished Professor of Physics and Astronomy at Purdue University. She holds courtesy appointments in the Lyle School of Civil Engineering and in the Department of Earth, Atmospheric and Planetary Sciences, also in the College of Science. Dr. Pyrak-Nolte holds a B.S. in Engineering Science from the State University of New York at Buffalo, an M.S. in Geophysics from Virginia Polytechnic Institute and State University, and a Ph.D. in Materials Science and Mineral Engineering from the University of California at Berkeley.

She is a member of the American Academy of Arts and Sciences, the National Academy of Engineering, and a Fellow of the American Geophysical Union. In 2020 Pyrak-Nolte was awarded the Society of Exploration Geophysicists Reginald Fessenden Award. She is the former President of the International Society of Porous Media, former President of the American Rock Mechanics Association and former Vice-President for North America for the International Society of Rock Mechanics and Rock Engineering. Her research interests include fractures, experimental and theoretical seismic wave propagation, laboratory rock mechanics, micro-fluidics, particle swarms, and fluid flow through Earth materials.

Speaker



Laura J. Pyrak-Nolte

Distinguished Professor | Purdue University

Moderators



Yida Zhang

Associate Professor | University of Colorado Boulder

MS 007: Advances in Computer Vision, Deep Learning, & Artificial Intelligence for Structural Monitoring, Inspections, and Digital Twins

2:15 PM – 3:35 PM | Location: HUMN 250

Chair(s): Vedhus Hoskere; Mohammad Jahanshahi; Jian Li; Wei Song

Moderatorss



Mohammad Jahanshahi

Associate Professor | Purdue University



Jian Li

Deane E. Ackers Professor | University of Kansas

ID 636: Edge Computing-Based Image Acquisition and Stitching for Infrastructure Inspection in Confined Environments

2:15 PM – 2:35 PM

Author(s): Shufan Liu, Purdue University; Shanyue Guan, Purdue University; ChengCheng Tao, Purdue University; Huaixiao Yan, Purdue University; Yongfei Li, Purdue University; Xiaoli Xiong, Purdue University

Structural health monitoring (SHM) in confined spaces such as pipelines, bridge interiors, and tunnel linings presents significant challenges in obtaining comprehensive visual documentation due to limited field of view and limited operational space. SHM conducted in confined environments often presents several challenges, including: (1) incomplete image coverage and severe fisheye distortion, (2) feature-based image misalignment under varying illumination and texture conditions, and (3) geometric distortion in overlapping regions.

To address these challenges, this paper proposes an integrated image acquisition and reconstruction framework for confined and restricted environments. The framework employs an edge computing-based dual fisheye camera system to capture wide-angle images, followed by a three-stage processing pipeline. First, fisheye images of structural conditions captured from dual cameras are corrected using optimized camera intrinsic parameters. Second, an enhanced Scale-Invariant Feature Transform (SIFT)-based feature matching algorithm with multi-parameter optimization is employed to achieve optimal performance by adaptively selecting parameter sets based on scene characteristics. Third, a distortion-controlled stitching algorithm incorporating homography validation, stretch ratio analysis, and gradient-based seam finding is applied to generate high-quality panoramic images while suppressing ghosting artifacts.

A series of laboratory experiments demonstrate the system's capability to effectively capture approximately 20 to 30 cm² coverage areas when the cameras are positioned 3 to 5 cm from the object surface in confined spaces. The system successfully acquires image pairs at a rate of one pair per second, with mean inlier ratios exceeding 70% and homography matrix condition numbers below 10⁶. The proposed approach also effectively excludes invalid regions and adaptively crops over-stretched areas, resulting in geometrically consistent panoramas suitable for quantitative defect measurement and analysis. This work provides a promising automated pipeline for complete image acquisition in confined infrastructure environments, enabling comprehensive visual inspection without extensive manual intervention.

Keywords: Structural health monitoring, fisheye camera, image stitching, confined space inspection, feature matching, distortion correction, edge computing

Speaker



Liu Shufan
Purdue University

ID 663: Error Analysis and Prediction of Structural Motion Measured by Stereo Vision Systems

2:35 PM – 2:55 PM

Author(s): Garrett Jankord, Colorado State University; Liang Hu, University of Notre Dame; Yanlin Guo, Colorado State University

In structural health monitoring (SHM), computer vision-based methods have emerged as a promising non-contact solution for measuring structural responses. Such a method usually employs a stereo vision system consisting of two digital cameras to record image sequences of a moving structure and then applies geometric principles to reconstruct the motion. The measurement process mainly consists of a few major steps, including camera calibration, image rectification, target tracking, and reconstruction. The accuracy of the measured structural motion thus depends jointly on the performance and errors of these major stages.

This study aims to evaluate the impact and propagation of errors within a stereo vision system. To this end, an error model is developed to predict the errors in the final reconstructed results as a function of key input parameters, including ground sampling density (GSD), motion amplitude, and motion frequency. In this study, the stereo vision methodology is first detailed by focusing on the introduction, impact, and propagation of approximation errors in the camera calibration, image rectification, and target tracking steps. The impacts of the error sources propagating to the reconstructed target positions are then evaluated through physical and numerical experiments. Based on the evaluation and experimental results, a global error prediction model is proposed. The error model treats two distinct error sources separately, i.e., the calibration and rectification errors and the target tracking errors. A procedure for predicting the impacts of calibration and rectification errors is developed using the virtual and rectified GSDs as governing input parameters. Note that the difference between virtual and rectified GSDs arises from the differences in the virtual camera parameters and rectifications. Furthermore, a regression model for predicting the tracking error (Lucas-Kanade optical flow) on a frame-by-frame basis with motion parameters as key model inputs, specifically the motions amplitude, frequency, and stereo head's GSD, is calibrated and verified. Combining the two error prediction methods yields the global error prediction model for the stereo vision system. As validated by comparing viable predictions with preliminary laboratory experiments, the results of this study indicate that the global error originating from camera calibration, image rectification, and target tracking can be effectively predicted by the proposed model.

Finally, an implementation procedure is presented for the proposed global error model. It is demonstrated that using the proposed model allows users to prescribe the expected accuracy of a stereo vision system following quick calibration and rectification tests. Alternatively, the model can be utilized with estimated input parameters, providing a faster, approximate but good enough, prediction of system accuracy. In such ways, the proposed model enables users to select optimal system configurations with significantly reduced experimental effort.

Speaker



Garrett Jankord
Graduate Research Assistant | Colorado State University

ID 709: Human-Centered Corrosion Inspection of Steel Bridges Using Augmented Reality and Meta-Ensemble Learning

2:55 PM – 3:15 PM

Author(s): Luke Attard, University of Kansas; Saeid Ataei, University of Kansas; William Collins, University of Kansas; Caroline Bennett, University of Kansas; Jian Li, University of Kansas

Reliable corrosion detection is essential for maintaining the safety and service life of steel bridges, yet conventional visual inspections remain labor-intensive, subjective, and difficult to document consistently. Recent advances in deep learning have improved automated corrosion detection from inspection imagery, but their practical impact depends on how effectively these predictions can be integrated into inspectors' field workflows. This study presents a human-centered corrosion inspection framework that combines augmented reality (AR) with AI-based corrosion detection to support more intuitive, efficient, and repeatable steel bridge inspections. By embedding AI outputs directly into the physical inspection environment, the proposed approach enhances inspectors' situational awareness and facilitates data-driven decision-making during field assessments.

The framework is implemented using the Magic Leap 2 AR headset, which enables real-time visualization of corrosion directly on steel bridge surfaces. A spatial mesh of the structure is generated in real time and serves as the geometric foundation for anchoring AI-detected corrosion with accurate spatial alignment. A Unity-based AR application is developed to project detected corrosion regions onto the spatial mesh and overlay them on the physical structure, allowing inspectors to view defects in situ and in proper geometric context. Corrosion detection is performed by a meta-ensemble learning architecture that integrates multiple deep learning models trained on diverse datasets and inspection conditions. The ensemble framework improves robustness and generalization by leveraging cross-model consensus and adaptive weighting, while suppressing spurious detections caused by surface texture, lighting variability, and environmental noise. Detected corrosion is stored using persistent spatial anchors, enabling inspectors to retrieve prior inspection results, compare corrosion states across multiple visits, and track progression over time. Experimental results demonstrate that the combined AR and meta-ensemble AI system improves inspection clarity, documentation efficiency, and consistency compared to conventional image-based workflows.

Speaker



Jian Li

Deane E. Ackers Professor | University of Kansas

ID 899: Vision-Based Assessment of Extrudability in 3D Printed Concrete Using Data-Efficient Machine Learning

3:15 PM – 3:35 PM

Author(s): Sama Taha, massachusetts institute of technology; Oral Buyukozturk, massachusetts institute of technology

Extrudability is a critical fresh-state property in extrusion-based additive manufacturing of cementitious materials, governing the geometric stability, surface quality, and buildability of printed layers. Inadequate extrudability can lead to layer discontinuities, edge collapse, surface roughness, or interlayer defects, which compromise both structural performance and constructability. Despite its importance, extrudability is most often assessed qualitatively through visual inspection during printing or through indirect rheological testing, limiting its scalability and real-time applicability in field or industrial settings.

This study explores the feasibility of a vision-based inspection framework for evaluating extrudability in 3D printed concrete using data-efficient machine learning approaches. The proposed concept leverages images captured during the printing process to classify printed layers into qualitative extrudability states (e.g., acceptable versus poor extrusion behavior) based on observable geometric and surface features. Rather than relying on large labeled datasets typically required for conventional convolutional neural networks, instead, pretrained computer vision models are employed to extract high-level visual features, which are subsequently analyzed using lightweight classifiers and few-shot learning techniques designed for data-scarce environments. This choice reflects practical constraints common in construction-scale additive manufacturing, where systematic image acquisition and labeling remain challenging.

Results indicate that pretrained visual representations capture mechanically meaningful characteristics of printed layers, enabling distinguishing between acceptable and defective extrusion behavior despite limited labeled data. The findings demonstrate the feasibility of vision-based extrudability assessment under realistic inspection conditions and highlight the potential of data-efficient learning strategies for quality evaluation in cementitious additive manufacturing.

This work presents a conceptual workflow, preliminary image analysis strategies, and discussion of model design considerations for small datasets, including variability in camera angle, lighting, and printing conditions. The proposed methodology is intended as a foundational step toward scalable, automated inspection tools for additive manufacturing with cementitious materials. While the current study focuses on feasibility and framework development rather than exhaustive model optimization, it highlights the potential of computer vision and data-efficient AI to enhance real-time quality assessment in construction-scale 3D printing. The approach aligns with broader efforts in vision-based inspection and AI-enabled monitoring for emerging construction technologies.

Speaker



Sama Taha

PhD Student @ MIT

MS 004: Computer vision and vibration-based damage identification using machine and deep learning

2:15 PM – 3:35 PM | Location: HUMN 135

Chair(s): YoungJin Cha; Oral Buyukozturk

Moderators



Youngjin Cha

Professor, F.ASCE, HCR | University of Manitoba

ID 139: Underwater Image Enhancement for Robust Structural Vibration Estimation in the Underwater Environment

2:15 PM – 2:35 PM

Author(s): Enjian Cai, University of Michigan-Dearborn; Zihan Wu, University of California San Diego; Michael D. Todd, University of California San Diego; Zhen Hu, University of Michigan-Dearborn

Structural Health Monitoring (SHM) of large civil infrastructure in inland waterways is difficult because the key components that need assessment are often underwater. Traditional sensors like strain gauges can measure structural responses, but they are limited by the small number of sensors and where they can be placed. Computer Vision (CV)-based methods offer a solution by providing measurements across the entire structure, thereby overcoming the limitations of using only a few sensors. However, these CV methods work poorly underwater because visibility is low, which may reduce image quality and make measurements less accurate. To solve this problem, this paper proposes a method that uses Physics-Based Graphics Models (PBGM) for Underwater Image Enhancement (UIE) to achieve accurate sub-pixel underwater vibration measurements. The approach works in three steps. First, PBGM creates large datasets that simulate different underwater conditions, thereby solving the problem of not having enough real underwater images with known reference data. Next, an Edge-Preserving Dual Attention Transformer (EDUT) with a special loss function removes image distortions while keeping important structural details needed for vibration analysis. Finally, a sub-pixel template matching technique measures the vibrations accurately. Testing on the Greenup miter gate in the United States shows the proposed method works well, with an average PSNR of 27.81 dB for image enhancement and vibration measurement accuracy between 0.0485 and 0.2319 pixels.

Speaker



Enjian Cai

Pstdoctoral research fellow | University of Michigan-Dearborn

ID 381: Hidden Crack Segmentation Using Multimodal Deep Learning with Multispectral Thermal Imaging

2:35 PM – 2:55 PM

Author(s): Elaheh MohammadiKhah, University of Manitoba; YoungJin Cha, University of Manitoba

Multispectral thermal imaging, as a non-destructive testing (NDT) method, has shown considerable potential for identifying surface and subsurface damage in concrete infrastructure. However, its effectiveness is significantly reduced when cracks are fully or partially covered by environmental contaminants such as mud. In such scenarios, surface-based inspection cues are obscured, and crack-induced thermal gradients are diminished due to changes in surface emissivity, moisture content, and heat transfer behavior. Under real-world service conditions, these factors significantly limit the reliability of conventional thermographic inspection for detecting hidden cracks. This study addresses these challenges by developing an advanced deep learning-based framework for the segmentation of concealed, naturally occurring cracks using multispectral thermal data.

To investigate these limitations under realistic field conditions, a controlled in situ data collection strategy was developed. RGB and multispectral image data were collected using a FLIR T650sc thermal camera from existing concrete pavement slabs containing naturally occurring cracks. The dataset includes cracks in different states, including exposed, partially covered, and fully covered conditions. The data collection protocol was designed to systematically examine the impact of mud coverage on crack detectability. Initially, RGB images of uncovered cracks were captured to establish accurate visual references for crack geometry. Subsequently, the cracks were covered with mud at controlled thicknesses to create partially and fully concealed conditions representative of realistic environmental exposure. After mud application, a stabilization period of approximately 5–6 hours was allowed to achieve thermal equilibrium between the mud layer and the concrete substrate, thereby ensuring uniform emissivity conditions. Following stabilization, MSX images were collected to capture fused thermal-visual responses associated with concealed crack regions.

Building on this dataset, the proposed deep learning model, termed MS-HCrackNet, incorporates a multi-branch encoder architecture that processes RGB and MSX inputs through separate feature extraction pathways to preserve modality-specific information. An attention-guided feature reweighting module is employed at the intermediate fusion stage to modulate multispectral feature representations, amplifying crack-related activations while suppressing background responses associated with mud coverage, moisture effects, and surface texture variability. To address the thin, elongated morphology of cracks and the spatially diffuse multispectral responses caused by surface concealment, the network leverages multi-scale feature representations to retain both fine crack details and broader contextual information. In addition, a boundary-preserving decoder with high-resolution feature reconstruction is used to maintain spatial resolution and boundary continuity during pixel-level segmentation.

The performance of MS-HCrackNet is evaluated using standard semantic segmentation metrics, including mean Intersection over Union (mIoU), precision, recall, and F1-score. The evaluation framework is designed to compare the proposed multispectral approach with RGB-only baselines commonly used in NDT applications. Preliminary observations and ongoing analyses suggest that integrating multispectral thermal information with attention-guided feature fusion improves the segmentation of cracks that are partially or fully concealed by mud, where visual cues are limited. These results are expected to demonstrate the potential of multispectral thermal imaging combined with advanced deep learning techniques to enhance the non-destructive identification of hidden cracks under realistic field conditions.

Speaker



Elaheh MohammadiKhah

Ms. | University of Manitoba

ID 376: Autonomous UAV-Based Advanced 3D Reconstruction for Structural Health Monitoring of Civil Infrastructure

2:55 PM – 3:15 PM

Author(s): Qasim Bin Saeed, University of Manitoba; YoungJin Cha, University of Manitoba

Traditional Neural Radiance Field (NeRF) techniques have demonstrated impressive capabilities for photo-realistic 3D reconstruction; however, their practical deployment in engineering contexts remains limited by substantial computational cost, long training times, and restrictive scene assumptions. Most conventional NeRF frameworks are optimized for small, bounded, and well-controlled environments, which makes them poorly suited for complex, unbounded, and cluttered real-world infrastructure such as bridges, buildings, and industrial facilities. These limitations significantly hinder their applicability to time-sensitive and large-scale civil engineering tasks.

To address these challenges, this study proposes a novel, high-accuracy 3D reconstruction pipeline specifically tailored for civil engineering applications, including Structural Health Monitoring (SHM) and construction management. The proposed framework integrates autonomous aerial data acquisition, advanced NeRF architectures, and immersive Virtual Reality (VR) visualization into a unified, end-to-end workflow. At the core of the method is a hybrid neural rendering architecture that combines the anti-aliasing and multi-scale scene representation strengths of Mip-NeRF 360—particularly effective for unbounded scenes—with the computational efficiency, robustness to illumination changes, and fast convergence of NeRF-W, Nerfacto, and Splatfacto. This fusion enables accurate and stable reconstruction of complex structural geometries while substantially reducing training time and resource demands, resulting in superior visual fidelity and geometric consistency under real-world conditions.

High-quality data acquisition is achieved through a deep learning-based autonomous Unmanned Aerial Vehicle (UAV) system equipped with obstacle-avoidance capabilities and fiducial marker-based localization. This approach ensures reliable pose estimation and consistent, comprehensive coverage of large-scale and hard-to-access structures, overcoming common challenges associated with GPS-denied or visually repetitive environments. Beyond geometric reconstruction, the pipeline incorporates automated crack segmentation directly within the neural 3D scene, enabling precise localization and visualization of structural anomalies for damage assessment.

Finally, the reconstructed neural scene is exported to Unreal Engine 5 to create an immersive VR environment, allowing engineers and inspectors to interactively explore, inspect, and analyze infrastructure in a realistic digital space. By seamlessly merging autonomous data capture, state-of-the-art neural rendering, automated damage detection, and interactive VR visualization, this study presents a scalable and practical solution for next-generation infrastructure monitoring, inspection, and management.

Speaker



Qasim Bin Saeed

Mr. | University of Manitoba

ID 90: Robust Unsupervised Damage Detection of Connectors in Modular Floating Structures under Varying Sea States

3:15 PM – 3:35 PM

Author(s): Siyun Park, University of Seoul; Sunjoong Kim, University of Seoul

Modular floating structures consist of multiple modules connected by mechanical connector systems, and connector damage can alter inter-module relative motion and global structural responses. However, direct inspection of connectors is often limited by site accessibility and is not suitable for continuous monitoring. This study presents a GANomaly-based unsupervised damage detection framework for identifying connector damage in modular floating structures using only intact data for training.

The experimental target is a 2-by-2 modular floating structure tested in a two-dimensional wave tank. Adjacent modules are connected by a spring-fender connector system, and connector damage is simulated by removing selected spring connections. Six-degree-of-freedom motion responses are measured under intact and damaged conditions for multiple sea states generated from JONSWAP spectra. Relative rotational responses between modules are converted into time-frequency matrices and used as inputs to the anomaly detection model.

A baseline GANomaly model is first trained to reconstruct intact response samples, and the latent discrepancy between the input and reconstructed latent representations is used to compute a damage index. Under a matched single sea-state condition, the baseline model already provides clear separation between intact and damaged responses, while latent normalization gives only limited additional improvement. However, when multiple sea states are included, the intact and damaged response distributions become more variable, and the baseline damage index shows stronger overlap between the two classes.

To reduce this sea-state sensitivity, latent normalization is applied to the latent representation used in both the encoder loss and anomaly score calculation. The results show that latent normalization improves intact-damage separation under larger sea-state variation and reduces misclassified samples compared with the baseline model. In a nearby unseen sea-state condition, latent normalization also reduces false-negative samples, indicating improved stability of the damage index when the test sea state is not included in training.

Overall, the results suggest that latent-normalized unsupervised generative modeling can improve connector damage detection in modular floating structures under varying sea states. Nevertheless, robustness remains limited under more strongly mismatched sea-state conditions.

Speaker



Siyun Park

Graduate student | Department of Civil Engineering, University of Seoul

MS 002: Repurposing Urban Data Streams for Scalable Infrastructure Monitoring

2:15 PM – 3:35 PM | Location: HUMN 125

Chair(s): Jingxiao Liu; Furkan Luleci; Liangfu Ge; Zhenkun Li; Debasish Jana; Valentina Giglioni

Moderators



Jingxiao Liu

Postdoc | UC Berkeley and LBNL

ID 366: LiDAR and Satellite-Based Sensing for Ground Movements

2:15 PM – 2:35 PM

Author(s): Bozhou Zhuang, University of California, Los Angeles (UCLA); Debasish Jana, Colorado State University; Sriram Narasimhan, University of California, Los Angeles (UCLA); Yousef Bozorgnia, University of California, Los Angeles (UCLA)

Accurate ground movement measurement is critical for geohazard assessment and infrastructure resilience. This study investigated two remote sensing modalities, airborne LiDAR and satellite imagery, to indirectly measure the ground movements. Dense optical flow was applied to optical satellite imagery, while point cloud registration was used for airborne LiDAR data. Specifically, the satellite-based approach uses ortho-processed imagery and the Farnebäck optical flow to estimate horizontal displacement at the pixel-wise resolution of 0.3 m. The LiDAR-based approach uses iterative closest point (ICP) registration to compute three-dimensional displacement fields at the resolution of 3 m. The two proposed workflows were evaluated and compared using multi-year datasets from two selected sites with recorded erosion and landslide activity. Results show that the displacement patterns estimated from the satellite imagery and LiDAR point clouds are in good agreement. The landslide observed during field inspections is identified by both methods. Satellite-based estimates are influenced by vegetation movement, whereas LiDAR-based displacement fields are less affected by canopies after ground point labeling. Overall, satellite imagery provides a cost-effective solution with broad coverage and higher resolutions, and airborne LiDAR offers more robust three-dimensional measurements. The results demonstrate the complementary value of combining satellite and LiDAR sensing for ground displacement monitoring in support of infrastructure resilience.

Speaker



Sriram Narasimhan

Professor | UCLA

ID 545: Bridge Monitoring Using Pre-Existing Telecommunication Fiber-Optic Networks

2:35 PM – 2:55 PM

Author(s): Jingxiao Liu, University of California, Berkeley; Jatin Aggarwal, Stanford University; Doyun Hwang, Stanford University; Biondo Biondi, Stanford University; Hae Young Noh, Stanford University

In this study, we introduce a scalable bridge health monitoring approach that leverages pre-existing telecommunication fiber-optic cables for distributed acoustic sensing (DAS) to capture a comprehensive range of bridge responses. We show, for the first time, that this approach enables (i) extraction of guided wavefields across entire bridge superstructures, which was previously infeasible without ultra-dense sensor arrays, and (ii) estimation of sub-millimeter quasi-static displacements using pre-existing telecommunication fibers.

Modern societies face escalating challenges from aging infrastructure, driven not only by physical deterioration but also by a lack of scalable, cost-effective, high-resolution structural condition data. While conventional sensing technologies such as cameras and wireless sensor networks have proven effective, their widespread deployment is often hindered by high costs, energy demands, communication requirements, and maintenance burdens. As urban environments grow in complexity and scale, these constraints limit the development of scalable monitoring solutions.

To overcome these limitations, our study integrates geophysical and structural monitoring approaches with the high spatial resolution of DAS by repurposing ubiquitous, pre-existing telecommunication fibers to measure guided wavefields, estimate modal parameters, and quantify quasi-static displacements. Through large-scale field evaluations on multiple bridges of diverse structural types in South Korea and the United States, we demonstrate that these measurements are robust to noise arising from imperfect fiber-bridge coupling, a limitation inherent to the non-dedicated nature of telecommunication fibers used as sensors.

Crucially, all these capabilities are achieved solely through existing telecommunication fibers, without the need for additional on-site sensors. While fiber-optic sensing is an established technology, the novelty of our work lies in redefining generic telecommunication fiber, originally deployed only for communication, as a large-scale, maintenance-free, high-accuracy sensing network for bridges and road infrastructure. By addressing long-standing challenges in sensor installation, maintenance, and durability, we show that pre-existing telecommunication fibers can support continuous, scalable, and cost-effective structural monitoring at a level not previously attainable.

Speaker



Jingxiao Liu

Postdoc | UC Berkeley and LBNL

ID 76: Graph-Based Deep Reinforcement Learning for Resilience-Oriented Decision-Making in Critical Infrastructure System

2:55 PM – 3:15 PM

Author(s): Xudong (Andrew) Fan, University at Buffalo; Jürgen Hackl, Princeton University; Xiong (Bill) Yu, Case Western Reserve University

Critical infrastructure systems (CIS), such as water distribution networks, road networks, and power networks, are often referred to as lifelines because they are essential for supporting the daily functioning of communities. The rapid expansion of CIS driven by urbanization has increased their vulnerability to high-consequence hazards, including earthquakes, flooding, and wildfires, thereby highlighting the urgent need for effective resilience-enhancement strategies. The resilience of a CIS is commonly defined as its ability to recover functionality following disruptive events, and sound repair-sequence decisions play a crucial role in achieving rapid and efficient recovery. This study presents the development of a Graph Convolutional Neural Network–integrated Deep Reinforcement Learning (GCN–DRL) framework to support optimal repair decisions aimed at improving CIS resilience under multiple hazard scenarios.

To demonstrate the effectiveness of the proposed GCN–DRL model, a water distribution network (WDN) and a road network subjected to earthquake and flooding hazards are used as case studies. Resilience evaluation frameworks for both systems are first developed, explicitly capturing the dynamic evolution of system performance during post-event recovery. For the WDN, the performance indicator accounts for the relative importance of service nodes and the extent to which post-earthquake water demands are satisfied. For the road network, the performance indicator reflects network connectivity under road segment closures. Within the GCN–DRL framework, the GCN encodes the structural and operational information of both the WDN and the road network. Network topology and node-level performance states (i.e., water demand satisfaction levels and road segment availability) are provided as inputs to the GCN, which outputs action-specific reward values. These values are then used by the DRL agent to identify optimal repair sequences from a large action space, with the objective of maximizing overall system resilience.

The repair strategies generated by the proposed GCN–DRL model are compared with those obtained using four conventional decision-making approaches. The results demonstrate that the GCN–DRL model consistently achieves the highest system resilience index (SRI) values and enables the fastest recovery of system performance. Furthermore, by leveraging transfer learning from pre-trained models, the proposed framework exhibits high computational efficiency when determining optimal repair sequences under new damage scenarios. Overall, the GCN–DRL model demonstrates strong robustness and generalizability, providing an effective decision-support tool for enhancing the resilience of interdependent infrastructure systems under multiple hazard conditions.

Speaker



Xudong Fan

Assistant Professor | University at Buffalo

ID 714: Investigating Fault Activation in Enhanced Geothermal Systems Using Microseismic and Low-Frequency Distributed Acoustic Sensing

3:15 PM – 3:35 PM

Author(s): Jingxiao Liu, Lawrence Berkeley National Laboratory; Linqing Luo, Lawrence Berkeley National Laboratory; Nori Nakata, Lawrence Berkeley National Laboratory

Enhanced geothermal systems (EGS) rely on hydraulic stimulation to enhance reservoir permeability, yet stimulation-induced fault activation remains a critical challenge for both reservoir performance and seismic hazard. In many EGS deployments, stimulation is intentionally designed to avoid direct intersection with mapped faults; nevertheless, seismicity is often observed on nearby faults, raising fundamental questions about the mechanisms by which stimulation perturbs fault stability. Understanding how injected fluids and the resulting stress perturbations interact with pre-existing faults, via pore-pressure diffusion, poroelastic stress transfer, or aseismic slip, is critical for interpreting induced seismicity and the underlying subsurface processes.

In this study, we investigate fault activation during stimulation of a horizontal-well EGS, where stimulation intervals are spatially separated from pre-existing faults. The system consists of parallel horizontal stimulation wells and a nearby vertical observation well instrumented with distributed acoustic sensing (DAS), enabling continuous monitoring of microseismicity and low-frequency strain-rate signals throughout stimulation. Microseismic events are detected, localized, and clustered in space and time to identify fault structures activated during injection. The resulting clusters reveal temporally evolving seismicity patterns associated with distinct fault geometries, which are further constrained using fault surface representations to infer fault orientation and fracture connectivity.

A key observation from the DAS data is that the depths of seismic events along one activated fault coincide with zones of tensile low-frequency DAS strain, suggesting a systematic relationship between fault-zone activation and seismicity. The low-frequency DAS signals are measured as strain-rate variations rather than direct displacement, providing spatially continuous but indirect constraints on fault deformation. This spatial correspondence motivates two hypotheses for the observed seismicity: (1) seismicity is driven by pore-pressure diffusion from stimulated fractures into the fault zone, progressively reducing effective normal stress over time; or (2) seismicity is triggered by poroelastic or elastic stress transfer associated with fault opening or aseismic slip, without requiring direct hydraulic communication at the seismic source locations.

To evaluate these mechanisms, we are developing a thermo-hydraulic model to simulate fluid diffusion and pressure evolution within fractures and faults, enabling estimation and characteristic pressure-propagation timescales. In parallel, we are using elastic dislocation modeling to quantify stress and strain changes associated with fault opening or slip, testing whether the observed low-frequency DAS strain patterns can be explained by mechanical deformation alone. By integrating DAS-based seismic and strain observations with thermal–hydraulic–mechanical modeling, this study can provide new constraints on fracture–fault interactions in EGS and advance understanding of subsurface processes governing induced seismicity, with implications for safer and more effective geothermal stimulation strategies.

Speaker



Jingxiao Liu

Postdoc | UC Berkeley and LBNL

MS 022: Integration of Physics-based Models with Data for Identification, Monitoring, Estimation, and Uncertainty Quantification

2:15 PM – 3:35 PM | Location: HUMN 1B50

Chair(s): Yang Wang; Hamed Ebrahimiyan; Babak Moaveni; Haeyoung Noh

Moderatorss



Yang Wang

Professor | Georgia Institute of Technology



Babak Moaveni

Professor | Tufts University

ID 313: Physics-Encoded Deep Learning CQC Method for Direct Floor Response Spectrum Estimation

2:15 PM – 2:35 PM

Author(s): Dongjin Kim, Seoul National University; Qiuji Ma, University of Toronto; Oh-Sung Kwon, University of Toronto; Junho Song, Seoul National University

For the seismic assessment of critical equipment and non-structural components, the accurate estimation of floor response spectra (FRS) is of critical importance. While conventional direct methods derive FRS from ground response spectra with high computational efficiency, they frequently yield overconservative estimations, particularly in near-resonance regions. This is because these methods rely on several simplifying assumptions embedded in classical modal combination rules, such as the use of white-noise excitation for cross-modal correlation calculations and the assumption of a common peak factor across all modal processes. Under realistic seismic excitations, these assumptions are often violated, leading to non-negligible predictive errors. To address these limitations, this study proposes a new direct FRS prediction method based on the complete quadratic combination (CQC) rule enhanced by a deep learning approach. The proposed method characterizes mode-dependent peak factors using physical principles grounded in random vibration theory, while parameters that are not analytically derivable are estimated using a data-driven deep neural network. This hybrid formulation supplements the traditional CQC framework with the proposed physics-encoded model to achieve accurate mean FRS estimates while preserving the analytical interpretability of the original method. The effectiveness of the proposed model is evaluated through numerical examples representing various structural systems, demonstrating its ability to mitigate overestimation in near-resonance regions compared to existing approaches.

Speaker



Dongjin Kim

Ph. D. Student | Seoul National University

ID 337: Physics-Based Model Calibration and Uncertainty Quantification of Transient Seepage in Levees Using Field Measurements

2:35 PM – 2:55 PM

Author(s): Hossein Bazdar, Tufts University; Farshid Vahedifard, Tufts University; Babak Moaveni, Tufts University

Levees are critical components of flood-protection systems that safeguard communities and essential infrastructure. Their performance and failure mechanisms, such as slope instability, piping, and uplift, are highly sensitive to the transient analysis of pore-water pressure (PWP). Consequently, numerical modeling of seepage plays a key role in levee safety assessment and risk-informed decision-making. This study presents a hybrid physics-based and data-driven model updating framework to improve the accuracy of transient levee seepage modeling. The proposed approach augments a finite-element (FE) transient seepage model with a residual-learning layer implemented using a Long Short-Term Memory (LSTM) neural network. The LSTM is trained to learn and correct the time-dependent residual error between FE-predicted and measured PWP, thereby compensating for model inadequacy. The framework is demonstrated using field monitoring data from the Qwuloolt Levee located in the State of Washington, where levee response is dominated by coupled tidal and climatic loading conditions. The proposed framework consists of (i) assembling tidal, meteorological, and pore-water pressure datasets; (ii) developing a two-dimensional transient seepage FE model with land-climate interaction boundary conditions; (iii) performing a global sensitivity analysis on the FE model using analysis of variance (ANOVA) to identify the dominant model parameters governing PWP response; (iv) calibrating the FE model in a reduced model parameter sub-space guided by sensitivity analysis results; and (v) training an LSTM network to predict residual errors using physically meaningful hydrologic and model-state features. Sensitivity analysis through ANOVA reveals that FE model behavior is dominated by a small subset of model parameters. Results show that the residual-learning framework substantially improves transient PWP prediction accuracy, reducing root-mean-square error by 70% after adding an LSTM correction layer, with the largest gains occurring during rapidly varying and extreme hydrologic conditions. Furthermore, TimeSHAP interpretability confirms that residual corrections are driven by physically sensible variables, such as rain and air temperature. The proposed framework here provides a generalizable, scalable and interpretable pathway which can be used toward sensor-informed digital twins for levees and other geotechnical systems governed by unsaturated flow, enhancing predictive reliability without increasing computational cost.

Speaker



Hossein Bazdar

Graduate Research Assistant | Tufts University

ID 541: Constrained Ensemble Kalman Inversion with DeepONet Surrogates for Finite-Element Model Updating: Application to Seismic Response of Dry Storage Casks

2:55 PM – 3:15 PM

Author(s): Ahmed Yaseen, University of Nevada Reno; Elnaz Seylabi, University of Nevada Reno

Calibrating computationally expensive, nonlinear finite element (FE) models remains a fundamental challenge in structural dynamics. This study presents a novel data assimilation framework that integrates constrained Ensemble Kalman Inversion (EnKI) for uncertainty-aware parameter estimation with multi-output Deep Operator Networks (DeepONet) as efficient surrogates for nonlinear structural response prediction. The constrained EnKI formulation enforces physically admissible parameter bounds while systematically incorporating observational uncertainty through particle-based sequential updates. To alleviate the prohibitive computational cost of repeated FE evaluations, a multi-output DeepONet surrogate is employed, achieving high-fidelity response predictions while reducing computational expense by orders of magnitude. The framework is validated using a dry storage cask (DSC) benchmark subjected to seismic loading, with emphasis on calibrating parameters that govern critical dynamic responses. Synthetic data studies demonstrate accurate parameter recovery and rapid convergence within a few assimilation iterations. Application to experimental shake table data from scaled DSC mock-ups shows substantial improvements in predictive accuracy, with model responses exhibiting excellent agreement with measured data. Although demonstrated for DSC systems, the proposed framework is system-agnostic and offers a robust, scalable methodology for calibrating nonlinear FE models across a broad range of structural dynamics applications.

Speaker



Elnaz Seylabi

Assistant Professor | University of Nevada Reno

ID 579: Hybrid Residual Learning for Unscented Kalman Filters

3:15 PM – 3:35 PM

Author(s): Shayan Mazloom, The Ohio State University; Abdollah Shafieezadeh, The Ohio State University; Jieun Hur, The Ohio State University; Jae-Wook Jung, Korea Atomic Energy Research Institute; Jeong-Gon Ha, Korea Atomic Energy Research Institute; Daegi Hahm, Korea Atomic Energy Research Institute

To address these limitations, we propose URAK-Net (Unscented Residual Augmented Kalman Network), a hybrid filtering framework that enhances the Unscented Kalman Filter by incorporating adaptive, data-driven corrections while preserving its core statistical structure. Rather than modifying the Kalman gain or abandoning the model-based estimator, the proposed approach introduces a flexible augmentation that enables the filter to accommodate persistent model inadequacies in nonlinear dynamic systems. This design allows the estimator to remain robust under evolving conditions while maintaining principled uncertainty propagation, bridging the gap between purely model-based filtering and learning-enhanced state estimation. Through numerical studies involving nonlinear dynamics with structural mismatch, URAK-Net demonstrates improved robustness and superior estimation accuracy compared to conventional UKF. These results highlight the potential of residual-in-process learning as a scalable and interpretable pathway for enhancing Bayesian filters in complex, real-world systems where accurate physical models are difficult to obtain.

Speaker



Shayan Mazloom

OSU

Ms 026: Modeling of Materials with Interfaces and Scales Using Physics-Based and Machine-Learning Methods

2:15 PM – 3:35 PM | Location: HUMN 150

Chair(s): Xiang Zhang; Pinlei Chen; Kamalendu Ghosh; Balavignesh Vemparala Narayana Murthy; Ravindra Duddu; Soheil Soghrati; Reza Abedi

Moderatorss



Kamalendu Ghosh

Sr. R&D Engineer | Micron Technology



Balavignesh Vemparala

Dr. | Synopsys, Inc.

ID 419: A gradient-enhanced phase-field model for ductile fracture at finite strain

2:15 PM – 2:35 PM

Author(s): Giang Huynh, Idaho National Laboratory; Benjamin Spencer, Idaho National Laboratory

Size effects and mesh objectivity remain central challenges in the modeling of inelastic deformation, damage evolution, and their interaction in solids. Because macroscopic failure mechanisms originate from material imperfections at the microscale, continuum formulations require characteristic length scales to capture the associated nonlocal effects. In this work, we propose a ductile fracture model applicable at finite strains within a general gradient framework, applied consistently to the relevant field variables.

The formulation generalizes classical local elastoplasticity and ductile fracture models, including the finite-strain elastoplasticity of Simo and Hughes [1] and the ductile phase-field fracture model of Borden [2] and recovers, as a special case, the extension of Wu's phase-field cohesive-zone model [3] originally developed for linear elasticity in the infinitesimal strain setting. A plastic length scale associated with the gradient of the hardening variable is introduced and coupled with the damage length scale in a modular construction of the framework. The resulting yield surface is derived directly from the energy functional based on the principles of maximum dissipation and isochoric plastic flow, while remaining amenable to further generalizations. Plastic yielding is evaluated locally, leading to a coupled local–global evolution of the internal variables formulated within an implicit nonlocal framework commonly employed in gradient damage models. Furthermore, an activation function linking the global hardening variable to the fracture toughness is introduced to regulate crack initiation under large plastic deformation. The performance and capabilities of the proposed model are demonstrated through a series of benchmark problems and experimental validations covering elastoplastic deformation and ductile fracture.

References

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[3] Jian-Ying Wu. A unified phase-field theory for the mechanics of damage and quasi-brittle failure. *Journal of the Mechanics and Physics of Solids*, 103:72–99, 2017.

Speaker



Giang Huynh

Government/National Lab Professional | Idaho National Laboratory

ID 439: Machine Learning-Enriched RKPM for Image-Based Modeling of Crack Propagation in Composite Materials

2:35 PM – 2:55 PM

Author(s): Yanran Wang, University of California San Diego; Jiun-Shyan (J.S.) Chen, University of California San Diego

Stress distributions and the corresponding fracture patterns and evolutions in the microstructures strongly influence the load-carrying capabilities of composite structures. This work presents a neural network-enriched and image-based reproducing kernel particle method (NN-RKPM [1]) for simulating the fracture mechanisms in composite microstructures. In the proposed method, a background interface-modified reproducing kernel (IM-RK) approximation is defined on a voxel-discretized model guided by the Support Vector Machine (SVM) material classification [2]. The pixel models are directly generated from X-ray microtomography image voxels, using voxel color code information. The background IM-RK approximation is enriched by a neural network (NN) approximation under the Partition of Unity framework. The NN approximation is driven by the minimization of the free energy, formulated based on a potential energy functional involving a phase field fracture model and an interface cohesive model. The NN hyperparameters are optimized to identify the location, orientation, and localization width of the evolving smeared crack paths in the solutions. The effectiveness of this method is demonstrated in modeling crack growth along interfaces as well as into matrix and inclusion subdomains and in predicting the corresponding structural-scale mechanical behavior in composite structures.

The proposed NN-RKPM framework is validated by numerical examples involving crack growth in heterogeneous microstructures, including single- and multi-inclusion configurations and an alumina-epoxy composite beam subjected to three-point bending. The results demonstrate that the method accurately captures the interaction between interfacial decohesion and bulk fracture, achieving excellent agreement with experimentally observed crack patterns while substantially reducing the total degrees of freedom compared to uniformly refined discretizations.

References

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Speaker



Wang Yanran

UCSD

ID 487: Effect of Spatial Correlation on Extreme-Value-Based Upscaling of Fatigue Nucleation

2:55 PM – 3:15 PM

Author(s): Anik Das Anto, The University of Tennessee Knoxville; Erdem Caliskan, Oak Ridge National Laboratory, The University of Tennessee Knoxville; Massimiliano Lupo Pasini, Oak Ridge National Laboratory; Stephanie TerMaath, The University of Tennessee Knoxville; Reza Abedi, The University of Tennessee Knoxville

Fatigue nucleation in polycrystalline metals is governed by highly localized extremes of cyclic plastic deformation rather than by averaged microstructural response. Crystal plasticity simulations capture these effects through full-field fatigue indicator parameter (FIP) distributions, revealing strong spatial heterogeneity associated with slip localization and microstructural interactions. However, directly simulating large enough domains to capture size effects and statistical variability is computationally prohibitive. As a result, there is a need for physically meaningful and computationally efficient approaches to upscale microstructural FIP information to larger length scales.

In this presentation, we introduce and compare two statistical upscaling approaches that use extreme-value concepts to predict fatigue nucleation from microstructural FIP fields. In the first approach, we treat the maximum FIP in each small statistical volume element as an independent quantity. We then study size effects by assembling larger domains from these SVE-level maxima using analytical extreme-value scaling, without explicitly accounting for spatial correlation between fatigue hot spots. This approach provides a simple and computationally efficient baseline for quantifying the evolution of extreme FIP values with increasing volume.

In the second approach, we explicitly account for spatial dependence by treating the microstructural FIP field as a spatially correlated random field. We characterize this dependence through correlation functions derived directly from the FIP field and use the resulting correlation length to quantify the effective number of statistically independent fatigue hot spots within a given domain. We then evaluate the extreme response of the correlated field using this correlation-informed description, enabling size-effect predictions that reflect spatial clustering of localization.

To enable efficient application of these upscaling frameworks beyond direct crystal plasticity simulations, we also demonstrate the use of a graph neural network (GNN) surrogate to predict per-grain FIP responses. Each microstructure is represented as a grain-adjacency graph (grains as nodes, crystallographic neighbors as edges), and the network outputs a maximum FIP value for each grain. These per-grain maxima enable rapid identification of fatigue-critical hot spots and provide the extreme-value inputs required for both correlation-unaware and correlation-aware extreme-value formulations, allowing rapid exploration of size effects and spatial correlation influences at a fraction of the computational cost.

We compare the correlation-unaware and correlation-aware approaches to assess the influence of spatial dependence on fatigue nucleation predictions. The results demonstrate that extreme-value-based metrics preserve fatigue-critical localization and provide a physically consistent alternative to grain-averaged measures, enabling efficient upscaling of microstructural simulation results to larger length scales.

Speaker



Anik Das Anto

Graduate Student | The University of Tennessee, Knoxville

MS 034: Machine Learning Applications in Natural Hazards Engineering for Enhancing Civil Infrastructure Resilience

2:15 PM – 3:35 PM | Location: HUMN 1B90

Chair(s): Pedro Fernandez-Caban; Haifeng Wang

Moderators



Pedro Fernandez-Caban

Assistant Professor | Florida State University

ID 181: Hypernetwork-Based Adaptive Response Prediction for Structural Dynamics

2:15 PM – 2:35 PM

Author(s): Dominik Weiss, ETH Zurich; Konstantinos Vlachas, ETH Zurich; Pantelis Vlachas, ETH Zurich; Eleni Chatzi, ETH Zurich

Infrastructure systems typically require continuous operation with minimal downtime, while subjected to high variability of environmental and operational loads and progressive damage and deterioration processes. Consequently, static models trained under fixed operational regimes often fail to generalize to changing conditions, thereby limiting their effectiveness for condition-based maintenance and decision-making in evolving operational contexts. This work attempts to address these challenges by leveraging PHLieNet, a recently proposed framework employing Parametric Hypernetworks for Learning Interpolated Networks.

PHLieNet relies on inferred embeddings that are tasked to modulate a hypernetwork responsible for generating the weights of dynamics propagation models. Via linear combinations of the inferred latent embeddings, the network can smoothly interpolate in the weight space and represent a continuous family of dynamics. The main contributions of this work are twofold: First, we attempt to extend the original framework to high-dimensional systems by integrating autoencoders that identify computationally tractable spaces for subsequent model generation. Second, a data-efficient adaptation strategy is explored to extend the validity of the trained models to new parameter regimes representing changing operational conditions. By incorporating additional learnable embeddings while keeping the core network fixed, the model can capture previously unseen dynamics corresponding to new operational conditions. This approach requires optimizing only a small subset of parameters, making it significantly more efficient than full model retraining. We demonstrate the effectiveness of this adaptive procedure on stochastically excited structural dynamic systems undergoing damage. The extended models maintain accurate and stable long-term predictions, enabling optimal maintenance planning and minimizing operational disruption.

Speaker



Konstantinos Vlachas

Lecturer | ETH Zurich

ID 262: Real-Time Urban Flood Forecasting Using a Machine-Learning Surrogate Trained on Automated HEC-RAS 2D Simulations

2:35 PM – 2:55 PM

Author(s): Muhammad Waqar Saleem, University of Missouri; Binbin Wang, University of Missouri

Accurate and timely flood prediction is essential for urban emergency response and infrastructure protection, yet the computational demands of two-dimensional hydrodynamic models limit their application in real-time decision support. This study develops a machine learning framework that combines the physical rigor of HEC-RAS 2D modeling with the computational efficiency required for operational flood forecasting in the Hinkson Creek watershed, Columbia, Missouri.

The proposed framework employs an automated HEC-RAS simulation pipeline to generate a comprehensive training database spanning diverse rainfall scenarios derived from local rain gauge networks. A machine learning surrogate model is trained to capture the complex nonlinear relationships between rainfall characteristics and spatially distributed flood responses, including inundation depths, flow velocities, and channel discharge across the urban floodplain. The surrogate model aims to preserve hydrodynamic fidelity while reducing prediction time from hours to seconds.

The framework integrates operational rainfall nowcasts and CMIP6 climate projections, enabling both real-time flood forecasting and long-term climate risk assessment. A web-based decision support tool is being developed to visualize predicted flood depths, identify vulnerable infrastructure, and generate actionable warnings for affected roadways and critical facilities.

Speaker



Binbin Wang

Associate Professor | University of Missouri

ID 450: PhyULSTM: Integrating Slow Feature U-net and LSTM with Physics-Based Regularisation for Seismic Surrogate Modeling

2:55 PM – 3:15 PM

Author(s): Sutirtha Biswas, Indian Institute of Technology (BHU) Varanasi; Kshitij Kumar Yadav, Indian Institute of Technology (BHU) Varanasi

Accurate and efficient prediction of seismic response is critical for designing and real-time monitoring of earthquake-resilient structures. Although physics-based numerical models, such as finite element analysis, offer reliable solutions, their substantial computational cost restricts their use in real-time analysis and large-scale simulations. In contrast, purely data-driven deep learning approaches often exhibit limited generalization and lack physical consistency, especially under previously unseen seismic excitations. The PhyULSTM overcomes these limitations. It is a hybrid physics-informed deep learning framework that combines a causal one-dimensional U-Net with a deep Long Short-Term Memory (LSTM) network for seismic surrogate modeling. The U-Net, originally developed for two-dimensional medical image segmentation, is adapted into a shallow, causal one-dimensional architecture inspired by the slow feature hypothesis. This adaptation enables effective multi-scale temporal feature extraction while maintaining strict sequence causality. The extracted features are then processed by an LSTM network to capture long-term temporal dependencies characteristic of nonlinear structural dynamics. To promote physical consistency, physics-based regularization is introduced through a finite difference-based tensor differentiator, which computes temporal derivatives of predicted state variables. Through the loss function, the model penalizes violations of the governing equations of motion during training. The PhyULSTM framework is validated using both numerical simulations of nonlinear single-degree-of-freedom systems and real-world seismic response data from instrumented buildings. Comparative results demonstrate that PhyULSTM consistently outperforms popular physics-informed deep learning models, including PhyCNN and PhyLSTM, in terms of prediction accuracy, correlation metrics, and hysteresis reconstruction. Notably, the proposed framework exhibits strong capability in capturing nonlinear hysteretic behavior and transient response characteristics, even when trained using acceleration-only measurements. Furthermore, PhyULSTM remains effective in a purely data-driven setting when explicit physical parameters are unavailable, highlighting its flexibility and practical relevance for real-world structural health monitoring and seismic response assessment. The results indicate that the proposed framework provides a robust, computationally efficient, and physically consistent surrogate modeling approach for nonlinear seismic response prediction.

Speaker



Sutirtha Biswas

Mr. | Indian Institute of Technology (BHU) Varanasi

ID 602: Leveraging Machine Learning to Predict Effective Roof Cover Age and Assess Roof Cover Vulnerability

3:15 PM – 3:35 PM

Author(s): Jorge Santiago-Hernandez, SageSure; Amin Enderami, SageSure; Arpit Bhusar, SageSure; Oscar Lafontaine, SageSure; Daniel Smith, SageSure

Over 90% of single-family homes are roofed with asphalt shingles in the U.S., where wind-induced roof-cover damage remains a dominant contributor to insured losses during hurricanes. Roofs are the main barrier between interior property features and nature, so any roof damage results in a cascade of subsequent losses. While wind uplift failure mechanisms in asphalt shingles are well characterized under controlled laboratory conditions, translating this knowledge into effective, scalable mitigation strategies for existing residential roofs has proven challenging. Limited field data on performance, shingle thickness and granule loss complicate vulnerability estimation and performance evaluation of aging asphalt shingle roofs. In addition, limited data on uncertain roof condition assessments and degradation of shingle adhesive bonds over time add to the uncertainty regarding the performance of a roof during a strong wind event. This study presents a machine-learning (ML) framework to (1) quantify the relationship between shingle roof cover deterioration and cumulative solar exposure including (UV) and infrared (IR), and (2) infer an effective roof-cover age that accounts for exposure-driven aging beyond chronological age alone. The framework leverages imagery and roof inspection data collected through aerial (drone-based) and in-person property inspections. The data comprises roof-level and segment-level observations spanning diverse roof geometries, material conditions, and geographic regions. Model inputs include measured counts of unsealed shingle within sampled roof areas, roof configuration indicators (e.g., slope, edges, ridges), and property attributes such as construction-year, roof installation year proxies and climate/exposure metrics derived from solar potential calculations. These features enable the model to capture both physical degradation mechanisms and environmental stressor influencing shingle performance.

Preliminary results suggest that UV and IR exposure can accelerate shingle aging and sealant degradation, leading to reduced roof-cover resilience under turbulent wind loading. This degradation results in lower uplift resistance and earlier failure progression, suggesting that reliance on chronological age alone may result in a systematic improper estimation of the roof vulnerability and associated insurance risk, ultimately reducing the chances an insured home is properly covered. These findings highlight cumulative solar exposure as a critical latent variable in roof vulnerability modeling and demonstrate the value of scalable, data-driven approaches for risk quantification and pricing.

Speaker



Jorge Santiago

Senior Manager, Home Services | SageSure Insurance

MS 086: Complex Dynamics Modeling and Vibration Control of Infrastructure Systems Under Single/Multiple Hazards

2:15 PM – 3:35 PM | Location: CLUB 4-5

Chair(s): Chao Sun; Mariantonieta Soto; Zhen Sun; Zili Zhang

Moderators



Chao Sun

Associate Professor | Louisiana State University

ID 662: A Molecular-Dynamics-Inspired Lattice Element Method for Dynamic Structural Response

2:15 PM – 2:35 PM

Author(s): Ermia Pourvaghar, University of Massachusetts Lowell; Mazdak Tootkaboni, University of Massachusetts Dartmouth; Arghavan Louhghalam, University of Massachusetts Lowell

Civil infrastructure systems are frequently subjected to extreme loading conditions caused by natural hazards such as hurricanes, floods, and earthquakes. These events induce dynamic loads that can significantly affect the performance and resilience of structures. Large-scale resilience assessment requires simulation models that are both computationally efficient and physically reliable. A Potential-of-Mean-Force (PMF)-based Lattice Element Method (LEM) has previously been developed to model buildings under quasi-static loading, offering an efficient alternative to complex Finite Element (FE) models for simulating both structural and non-structural components [1]. In LEM, the domain is discretized into a collection of particles whose interactions are governed by defined interaction potentials.

With quasi-static loading, however, the analysis is limited to post-event assessment and cannot capture transient dynamic response. This study extends the PMF-based LEM to a dynamic analysis framework by incorporating concepts from molecular dynamics simulations. Time integration schemes from molecular dynamics are adopted to model the dynamic response of buildings efficiently. The proposed dynamic LEM framework is implemented in the Large-scale Atomic/Molecular Massively Parallel Simulator (LAMMPS) using the Bonded Particle Model (BPM) package, which accounts for both translational and rotational degrees of freedom of particles. To enable the application of BPM within the PMF-based LEM framework, stiffness parameters in BPM are calibrated against PMF energy parameters using Euler–Bernoulli and Timoshenko beam theories. Furthermore, to address the lack of orthogonal bending capabilities in the original BPM formulation, which is an essential feature for simulating structural elements, a modified bond style within the BPM package is developed to capture bending behavior in two transverse directions with distinct stiffness values. Finally, the dynamic response of different types of buildings and frame structures under various loading conditions is simulated using the proposed framework. The accuracy of the results is validated through comparison with simulations performed in OpenSees, and the computational efficiency of the framework is evaluated.

References

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Speaker



Ermia Pourvaghar

PhD student | University of Massachusetts Lowell

ID 774: Experimental Investigation on Hydro-elastic Response of Sea-Crossing Cable-Stayed Bridge under Spatial Concurrent Wave and Current Conditions

2:35 PM – 2:55 PM

Author(s): Kai Wei, Southwest Jiaotong University; Haoyu Li, Southwest Jiaotong University

In the context of the swift advancement of globalization and urbanization, there has been a substantial increase in the demand for transportation infrastructure in coastal regions and islands. Sea - crossing bridges have become crucial infrastructure for connecting mainland areas with islands, thereby promoting economic integration and regional development. Nevertheless, the shift of bridge construction from inland to marine environments poses significant challenges, mainly due to the harsh and variable wave and current conditions, particularly during extreme weather events such as typhoons. Severe typhoons usually induce complex wave and current coupled environments in sea strait areas. On one hand, the direction of the current in the strait is relatively stable, while the wave direction is significantly influenced by the typhoon wind direction. There often exists a notable misalignment between waves and currents, and the spatial coupling problem of non-collinear (oblique) waves and currents is prominent. Some previous studies indicate that the spatial concurrent intersection of waves and currents can lead to the asymmetry of the wave surface, causing long-peak waves to evolve into short-peak waves, and even resulting in extreme waves or breaking waves, which may seriously threaten the safety of bridges. Existing research in bridge engineering has primarily concentrated on the hydrodynamic loads of bridge piers or foundations under collinear wave-current scenarios, with relatively less attention on those under the actual spatial concurrent wave-current conditions in the strait. On the other hand, the sea-crossing bridge usually has a long span with multiple foundations. There is obvious inconsistency in the wave-flow action at different foundations, which will have a significant impact on the response of the whole bridge structure. However, it is difficult and impossible to generate spatial concurrent wave and current conditions in the traditional flume facilities with the narrow and limited water widths. This study addressed the aforementioned issues by proposing a structural hydro-elastic experimental program of a sea-crossing cable-stayed bridge under spatial concurrent wave and current conditions. The experimental was conducted using the wave and current basin at Southwest Jiaotong University. The rectangular basin has a length of 70 m, width of 50 m and a maximum water depth of 3 m. It is equipped with a group of piston-type wavemakers on one short side and the distributed current pumps on all four sides of the basin, which can generate high-quality spatial concurrent wave and current conditions. A sea-crossing cable-stayed bridge scheme located in a water depth of 80 m was taken as the prototype. The experimental model was designed with a scale of 1:100 according to the geometry, Froude and dynamic similarities. To fulfill these similarities, the bridge model foundation model was made of thin-walled aluminum alloy tube and polylactic acid fiber materials. The model box girder was made of steel core beam, counterweight lead blocks and wooden shell. The dynamic responses, including tower acceleration, tower bottom reaction force, girder acceleration, etc., were measured for the whole bridge structure under wave only scenarios, current only scenarios, collinear wave-current scenarios, and spatial concurrent wave-current scenarios, respectively. The responses of the tower and main girder under different scenarios were compared to investigate the spatial coupling effect of non-collinear waves and currents on the dynamic behavior of the bridge. The research findings can serve as a valuable reference for ensuring the safety of bridges crossing large sea straits.

Speaker



Kai Wei

Professor | Southwest Jiaotong University

ID 963: Modeling Slab–Wall–Column Interaction in Tall Core Wall Buildings Under Earthquake Loading

2:55 PM – 3:15 PM

Author(s): Connie Chen, Exponent; Jack Moehle, University of California, Berkeley

Tall reinforced concrete buildings commonly employ core walls as the primary seismic force-resisting system, while unbonded post-tensioned slab–column framing is typically designed for gravity loads. Under lateral earthquake loads, the slab-column framing acts as an outrigger for the building and contributes to the overall overturning resistance. Overlooking or underestimating this outrigger effect could potentially lead to underestimation of column axial forces, misrepresentation of overall building dynamics, and unconservative predicted seismic demands. This presentation discusses a practical modeling approach for representing the nonlinear behavior of a slab-wall-column subassembly under lateral earthquake loading. The approach utilizes equivalent slab-beam elements with linear-elastic stiffness and concentrated nonlinear moment–rotation hinges at slab–wall and slab–column connections. Lateral stiffness is defined using the effective beam-width model, while connection strength and deformation capacity are determined using expected-strength calculations consistent with ACI 318.

The proposed modeling technique is calibrated using experimental results from laboratory tests of a post-tensioned slab–wall–column subassembly under reversed cyclic lateral loading. Comparisons between analytical simulations and measured force–displacement responses demonstrate that the technique accurately predicts initial lateral stiffness, peak strength, and key nonlinear characteristics governing outrigger behavior, particularly for loading that induces hogging rotation at the slab–column connection. Application of the technique to an archetypal 40-story tall building illustrates its implications for gravity system design and highlights the impact of neglecting complex interaction effects on predicted seismic demands. Including outrigger action of the slab-column gravity framing in design load combinations produces a measurable increase in gravity column axial forces at a typical story level, emphasizing the potential for unconservative designs if the slab–wall–column interaction is neglected.

Speaker



Connie Chen

Senior Engineer | Exponent

ID 979: Development of Response-Based Decoupling Criteria for Acceleration-Sensitive Nonstructural Components

3:15 PM – 3:35 PM

Author(s): Goktug Tufekci, University of California, Berkeley; Dimitrios Konstantinidis, University of California, Berkeley

Decoupled analysis is widely used to assess seismic demands on nonstructural components (NSCs): the primary structure is analyzed first to generate floor motions, and NSCs are subsequently analyzed as secondary systems subjected to the floor motions. While this workflow is efficient, it does not guarantee accuracy when dynamic interaction between the primary and secondary systems is non-negligible, particularly in regimes where tuning and closely spaced modes can cause small changes in the combined dynamics to produce large changes in the NSC response. Existing decoupling criteria are based on changes in primary modal properties or transfer-function variation, failing to bound the error in the NSC demand parameter. This study develops a response-based decoupling framework formulated directly in terms of the secondary system response. For linear primary–secondary systems, coupled and decoupled representations of NSC absolute acceleration are derived in closed form in terms of the modal properties of the primary structure and the dynamic parameters of the NSC. A variance-based decoupling index is introduced as the ratio of decoupled to coupled second-moment response measures, expressed as a spectrally weighted integral of the NSC acceleration transfer function. The weighting can be based on a design-spectrum-consistent power spectral density (PSD) model or computed from record-specific spectra, enabling a consistent connection between the criterion and the excitation description used in practice. The formulation explicitly retains cross-modal terms through the response cross-spectral density, thereby quantifying the effect of closely spaced modes on decoupling error. To extend the theory beyond idealized single-point attachments, the primary subsystem is represented at the NSC interface by a frequency-dependent dynamic stiffness obtained through boundary condensation. This admits multi-degree attachment sets and captures slab flexibility and local behavior without assembling large coupled finite-element models for each NSC configuration. In this setting, the interaction is characterized through the relative magnitude and frequency dependence of the secondary dynamic stiffness compared to the condensed primary dynamic stiffness in the spectrally relevant band. The resulting framework produces decoupling maps and acceptance criteria for a prescribed tolerance parameterized by frequency ratio, effective modal mass ratio, and modal damping. This provides a unified basis for evaluating decoupling for both horizontal and vertical response components through the same dynamic stiffness-based coupling formulation with direction-specific spectral weighting. Numerical results demonstrate the emergence of distinct error regimes near tuning and away from resonance and illustrate how slab flexibility and attachment configuration modify the boundary of acceptable decoupling for a prescribed response-error tolerance.

Speaker



Goktug Tufekci

PhD Student | University of California, Berkeley

MS 038: Mechanics and Modeling of Durable and Resilient Pavements

2:15 PM – 3:35 PM | Location: CASE E230

Chair(s): Jamilla Teixeira; Shane Underwood; Nam Tran; Ramez Hajj

Moderators



Jamilla Teixeira

Assistant Professor | University of Nebraska

ID 843: Validation of Permanent Deformation using Pavement Analysis Using Nonlinear Damage Approach (PANDA) against test sections at National Airport Pavement and Materials Research Center (NAPMRC)

2:15 PM – 2:35 PM

Author(s): Ghaith Khresat, Texas A&M University; Masoud Darabi, The university of Kansas

This study evaluates the capability of the Pavement Analysis Using the Nonlinear Damage Approach (PANDA-AP) framework to predict permanent deformation (rutting) in airfield asphalt layers subjected to high tire pressures and extreme temperature conditions. PANDA-AP integrates mechanistic constitutive models from the literature that account for nonlinear viscoelasticity and viscoplasticity, enabling accurate representation of asphalt mixture behavior under complex loading. Laboratory repeated creep–recovery tests conducted over a range of stress levels are used to calibrate the material parameters governing the nonlinear viscoelastic and viscoplastic responses of different asphalt binders. These calibrated constitutive relationships are implemented within finite element models of pavement structures to simulate rutting accumulation observed in full-scale test sections at the National Airport Pavement and Materials Research Centre (NAPMRC).

A systematic comparison between two-dimensional and three-dimensional finite element representations of the pavement system is performed to assess the influence of dimensional modeling assumptions on predicted permanent deformation. In addition, the effects of tangential and longitudinal shear stresses, in combination with vertical compressive stresses, are investigated to capture the multi-axial stress state induced by aircraft loadings. Model predictions of rut depth evolution show close agreement with measured field performance data, demonstrating the robustness of the PANDA-AP constitutive framework and its finite element implementation. The predictive accuracy across binder types and environmental conditions underscores PANDA-AP's potential as a performance-based analysis tool for airfield pavements.

The results illustrate that incorporating nonlinear damage mechanics and multi-directional stress effects significantly enhances the fidelity of rutting predictions relative to traditional linear viscoelastic or empirical approaches. Furthermore, PANDA-AP enables estimation of the number of loading cycles to specific rutting thresholds, offering valuable insights for pavement design and life-cycle assessment. These findings support the integration of advanced mechanistic damage models into design and evaluation workflows to improve reliability and performance prediction for pavements under extreme operational demands.

Speaker



Ghaith Khresat

Postdoctoral researcher | Texas A&M University

ID 875: Effects of RAP aging level on non-linear viscoelastic cohesive zone model parameters of recycled asphalt mixtures

2:35 PM – 2:55 PM

Author(s): Farzad Yazdipناه, University of Nebraska-Lincoln; Jamilla Teixeira, University of Nebraska-Lincoln

This study investigates the effects of reclaimed asphalt pavement (RAP) aging level on cracking evolution of RAP-recycled asphalt mixtures using a finite element nonlinear viscoelastic cohesive zone (NVCZ) model. Nine RAP-recycled asphalt mixtures, varying in RAP content and aging level, were experimentally characterized using dynamic modulus (DM) and semicircular bending (SCB) tests to obtain model linear viscoelastic (LVE) and CZ fracture parameters. A systematic parametric analysis was conducted to evaluate the sensitivity of model parameters and their influence on the simulated fracture response. Model parameters were also interpreted in terms of their physical meaning to establish procedures for estimating their values based on RAP aging level and RAP content. Crack initiation and crack propagation phases were separated based on numerical predictions, enabling investigation of how damage evolution depends on RAP aging level. Results indicated that RAP aging level primarily governs the onset of cracking, while RAP content amplifies this effect once the RAP binder becomes sufficiently aged. Finally, analytical relationships obtained from numerical modeling were used to derive shift factors for predicting damage parameters and mixture stiffness as functions of RAP classification. These outcomes, combined with RAP classification based on binder rheological and chemical parameters, were used to establish a framework for optimizing the design of RAP-recycled mixtures using the proposed NVCZ approach.

Speaker



Farzad Yazdipناه

Ph.D. Candidate | University of Nebraska Lincoln

ID 897: Coupled Hydromechanical Modeling of Moisture Diffusion and Damage Evolution in Flexible Pavements

2:55 PM – 3:15 PM

Author(s): Ryah Nadjafi, University of Colorado Boulder; Maryam Shakiba, University of Colorado Boulder

This study investigates how the coupled effects of moisture diffusion and pore water pressure promote pavement degradation using finite-element analysis through a series of parametric comparisons. The increasing frequency of extreme weather events, particularly flooding, increases the rate of material degradation in flexible pavements. Coastal roadway networks face an intensified threat: the high salinity of seawater. Rising sea levels exacerbate these risks as coastal pavements are more frequently exposed to soluble salts that weaken internal bonds, promote cracking, and reduce pavement strength more aggressively than freshwater alone [1]. Additionally, traffic loading induces pore pressure within cracks and voids of pavement structure, breaking down the integrity of the pavement faster than traffic load on dry pavement. Internal stresses in turn accelerate crack evolution and propagation, decreasing the time-dependent stiffness and strength of asphalt concrete. Despite the detrimental effects of moisture and mechanical damage in asphalt pavements, there is no three-dimensional finite-element model at the macroscale that simulates the coupled effects of pore water pressure, diffusion of saltwater, and mechanical tire loading.

To address this issue, this work evaluates pavement structural response by varying saltwater concentration and depth of the groundwater table. A three-dimensional simulation for a pavement section under a moving tire load was implemented in Abaqus finite-element software via the Pavement Analysis using Nonlinear Damage Approach (PANDA), a finite-element code developed at Texas A&M University [2]. This work builds upon previous microscale moisture diffusion and macroscale pore pressure models that have used PANDA. The finite-element model developed simultaneously captures internal stresses due to void saturation as well as diffusion of moisture from the surface. Saltwater diffusion is considered via Fick's diffusion law, and pore water pressure is based on Biot consolidation theory. Material response and damage evolution is integrated using PANDA, which includes validated, nonlinear viscoelastic and viscodamage (moisture and mechanical) constitutive relationships for asphalt concrete. The outcome indicates that neglecting the effects of high-salinity, coastal floodwaters underestimates pavement damage when compared to freshwater flood events. Consequently, considering the coupled mechanisms of pore water pressure and moisture diffusion results in improved damage predictions for application in coastal region pavement design and maintenance planning.

Keywords: Asphalt concrete, moisture-induced damage, flooded pavement, continuum damage mechanics

References:

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Speaker



Ryah Nadjafi

University of Colorado Boulder

ID 964: Mechanistic Assessment of Binder Rejuvenation and Tensile Performance in 100% RAP Asphalt Mixtures

3:15 PM – 3:35 PM

Author(s): Jeffrey Krebs, Colorado State University Pueblo; Jacob Kuhn, Colorado State University Pueblo; Md Islam, Colorado State University Pueblo; Chris Wacinski, Driven Plastics; Gregory George, Pueblo County; Saqib Gulzar, Colorado State University Pueblo; Hasan Faisal, Colorado State University Pueblo

This study investigates the performance of a novel bio-based rejuvenator, in restoring binder behavior in asphalt mixes produced with 100% Reclaimed Asphalt Pavement (RAP). RAP was collected from Pueblo West County stockpiles for intended use in patching and surface-layer applications. The work was conducted in two phases. In Phase 1, the rejuvenator was dosed at 0%, 1%, 2%, 3%, and 5% by binder weight. Each mix was prepared at temperatures consistent with field practices and compacted to evaluate volumetric and mechanical performance. The RAP had 5.32% binder content and a Gmm of 2.443. All mixes satisfied Colorado Department of Transportation (CDOT) volumetric design requirements, with air voids between 2% and 5%, VMA from 19.4% to 22.1%, and VFA ranging from 77% to 90%. RAP gradation remained stable after ignition testing, confirming structural consistency. Indirect tensile strength (ITS) testing revealed a reduction in breaking force with increased rejuvenator content: the 0% mix averaged 4953 and 3610 lb, 0.5% dosage samples averaged between 3428 and 3841 lb, 0.75% dosage showed 1625–2760 lb, and the 1% dosage resulted in values of 1689 and 1974 lb. These reductions indicate softening effects consistent with improved binder flexibility but reduced tensile resistance. Phase 2 refined the dosage window to 0%–1%, confirming the 0.5%–1% range offers a balance between flexibility and structural performance. The 0.75% dosage demonstrated the narrowest data spread and stable ITS, suggesting improved consistency. The 1% dosage offered reduced strength but better workability and compaction behavior. Overall, the results suggest the rejuvenator is effective in softening aged RAP binder, with optimal benefits observed at or below 1%. Excessive dosages compromise tensile strength, making them less desirable for load-bearing applications. Field implementations have adopted the 0.75% dosage based on these findings. This research supports the strategic use of this novel rejuvenator in 100% RAP mixes and offers a foundation for lifecycle performance evaluation under field conditions.

Speaker



Hasan Faisal

Colorado State University Pueblo

MS 061: Topology Optimization: from Algorithmic Developments to Applications

2:15 PM – 3:35 PM | Location: CASE E240

Chair(s): Mazdak Tootkaboni; Chuan Luo; Josephine Carstensen; Shelly Zhang; James Guest

Moderatorss



Hajin Kim-Tackowiak

PhD | MIT



Yash Agrawal

Mr. | Johns Hopkins University

ID 500: Topology optimization of anisotropic multi-material structures under local stress constraints

2:15 PM – 2:35 PM

Author(s): Juan Pablo Giraldo-Isaza, University of Missouri; Oliver Giraldo-Londoño, University of Missouri

Recent advances in multi-material topology optimization (TO) and additive manufacturing (AM) have enabled the design of lightweight, high-performance structures that exploit the complementary mechanical properties of different materials [1]. Yet a persistent gap remains between computational designs and their physical performance after fabrication, as most existing TO approaches assume isotropic material behavior and overlook AM-related anisotropy. In particular, most existing formulations ignore the direction-dependent strength resulting from the layer-by-layer deposition process, which often leads to optimized parts that fail prematurely when loaded.

To address this limitation, we introduce a stress-constrained multi-material TO framework that explicitly accounts for AM-induced material anisotropy. The framework incorporates two direction-dependent failure criteria, namely the Tsai–Wu and Liu–Huang–Stout criteria, enabling the representation of anisotropic strength in printed components. The resulting locally constrained TO problem is solved using an augmented Lagrangian formulation [1,2] to ensure computational efficiency, robustness, and scalability.

A key feature of the approach is its modularity and generality, as it allows isotropic and anisotropic materials to be modeled simultaneously within a unified optimization setting to model a broad range of material systems. This flexibility enables a broad range of applications, including multi-material polymer structures fabricated via AM, concrete retrofitting using fiber-reinforced polymer (FRP) sheets, and hybrid designs combining anisotropic (e.g., wood, FRP) and isotropic (e.g., metal) components. In this presentation, we detail the formulation and discuss several numerical examples demonstrating that exploiting anisotropic material behavior and hybrid systems can substantially reduce structural mass while satisfying local material failure constraints.

References

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Speaker



Juan Pablo Giraldo

PhD Candidate | University of Missouri

ID L3: Two-state topology optimization for adaptable structures

2:35 PM – 2:55 PM

Recent work has shown the ability to electrochemically alter topology, providing a potential mechanism to enable adaptable structures [1]. We can now conceptualize a new class of structures where minor topological changes achieve new functional capabilities. For example, navigating between two distinct topologies that are activated by connecting or disconnecting load paths. The component serves different functions in each of these configurations with drastically different mechanical responses but a small difference in material distribution. We present a topology optimization framework for the design of such structures. The approach is based on the Heaviside projection methodology [2] where we design the original structure layout as well as the location of the connections/disconnections of the modified structure. This approach is demonstrated for stiffness manipulation cases where a drastic change in stiffness is desired between the two topologies. We also present the design of a family of compliant mechanisms with different functionalities by connecting/disconnecting major struts.

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[2] Guest, J.K., Prévost, J.H. and Belytschko, T. (2004), Achieving minimum length scale in topology optimization using nodal design variables and projection functions. Int. J. Numer. Meth. Engng., 61: 238-254. <https://doi.org/10.1002/nme.1064>

Speaker



Yash Agrawal

Mr. | Johns Hopkins University

ID 549: Optimal Reinforcement Layout in Anisotropic 3D Printed Concrete Structures with Mechanical and Connectivity Constraints

2:55 PM – 3:15 PM

Author(s): Sri Keerthana Chakravarthula, Texas A&M University; Petros Sideris, Texas A&M University; Eric Kreiger, Construction Engineering Research Laboratory (CERL) - Engineer Research and Development Center (ERDC) - US Army Corps of Engineers (USACE)

This study develops a topology optimization framework for 3D printed concrete structures that simultaneously designs the concrete material configuration and the reinforcement layout. In concrete 3D printing, reinforcement in the form of cables or wires is often deposited at layer interfaces, unlike molded concrete structures where the reinforcement is included at fixed, predefined locations. Existing topology optimization approaches either treat reinforcement as fixed, thus not adopting to the layer orientation, or as a concrete-reinforcement homogenized material, or introduce it through post processing, which limits the ability to capture design scale interaction between concrete and reinforcement.

The proposed framework attempts to address these limitations by modeling reinforcement as a discrete truss network with moving nodes embedded within a continuous concrete domain, allowing both materials to evolve in a coupled manner during optimization. A dense ground structure defines the initial reinforcement design space, where each truss element represents a potential reinforcement path. A key contribution of this work is the introduction of design scale stiffness contribution factors that regulate the relative influence of concrete and reinforcement in the global stiffness matrix. These factors penalize reinforcement misalignment with the layer orientation and ensure that steel remains embedded within concrete, promoting physically meaningful interaction between the two materials. Additional constraints are introduced to prevent overlapping or intersecting reinforcement members, ensuring continuous and feasible reinforcement paths that are compatible with layer wise printing. Furthermore, the spatial coordinates of reinforcement nodes are treated as design variables, allowing limited movement of nodes to improve reinforcement placement and alignment with principal stress directions. This flexibility enables the reinforcement network to reconfigure locally rather than being restricted to a fixed ground structure. The framework also supports simultaneous optimization of reinforcement layout and concrete material distribution while accounting for printing direction, allowing reinforcement to develop consistently with anisotropic concrete behavior.

The proposed formulation is solved using an Augmented Lagrangian method with the Method of Moving Asymptotes as the underlying optimizer. Nodal displacement and local stress constraints are incorporated to ensure structural performance, including stress constraints on reinforcement members to prevent yielding. Numerical examples are used to demonstrate the behavior of the proposed framework. These examples illustrate the development of reinforcement paths aligned with dominant stress flow, the coupled evolution of concrete and reinforcement, and the influence of printing direction on optimized designs.

Speaker



Sri Keerthana Chakravarthula

Ph.D. Student | Texas A&M University

ID 617: Uncertainty Aware Multi Scale Design of Stress Constrained Mechanical Metamaterials

3:15 PM – 3:35 PM

Author(s): Abhinav Gupta, Vanderbilt University; Ravindra Duddu, Vanderbilt University; Rajib Chowdhury, Indian Institute of Technology Roorkee

Uncertainty aware design of mechanical metamaterials is essential for achieving reliable performance in applications governed by stress localization and dynamic loading. In this talk, I will discuss a multi scale computational framework for the design of three dimensional mechanical metamaterials that integrates stress constrained topology optimization, robust formulations under uncertainty, and homogenization based scale coupling.

At the microscale, periodic unit cell architectures are designed using stress based topology optimization to explicitly control local stress concentrations while achieving prescribed effective mechanical properties (Gupta et al., 2024). The formulation emphasizes strength driven microstructure design, where local stress measures are directly incorporated into the optimization problem to mitigate stress amplification and failure sensitive regions. Robust topology optimization strategies are employed to incorporate material uncertainty in auxetic metamaterials, enabling the design of microstructures whose effective response remains stable under variations in material parameters (Agrawal et al., 2022). These formulations address key challenges associated with sensitivity of optimized microarchitectures to uncertainty (Saurabh et al., 2025).

The optimized unit cells are homogenized to compute effective constitutive responses and subsequently embedded into macroscale models, enabling spatially varying stiffness and strength through an explicit multi-scale design strategy. This coupling allows macroscale stress fields and loading conditions to directly inform local unit cell design targets, ensuring consistency between microstructural behavior and overall structural response. The influence of topological control parameters on effective properties and stress response is also examined to understand the emergence of extreme mechanical behavior in architected materials.

The framework is demonstrated through numerical and experimental studies on extreme mechanical metamaterials, with particular emphasis on high velocity impact and energy absorption behavior of topology optimized auxetic metamaterials. These studies highlight the role of microstructural topology and stress redistribution in governing dynamic response and impact resistance, illustrating the potential of uncertainty aware, stress constrained multi scale design for advanced mechanical metamaterials.

References

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Speaker



Abhinav Gupta

Research Assistant Professor | Vanderbilt University

MS 053: Tensegrity – Form finding, analysis, mechanical behaviour, control, and design of tensegrity and tensegrity-like systems

2:15 PM – 3:35 PM | Location: KTCH 1B87

Chair(s): Landolf Rhode-Barbarigos; Muhao Chen; Ajay Harish

Moderators



Landolf Rhode-Barbarigos

Associate Professor | University of Miami

ID 243: Form finding and analysis of 3D super-stable tensegrities

2:15 PM – 2:35 PM

Author(s): Borui Xu, The Department of Civil and Environmental Engineering, Princeton University; Xiangxin Dang, The Department of Civil and Environmental Engineering, Princeton University; Glaucio Paulino, The Department of Civil and Environmental Engineering, Princeton University

Super-stable tensegrity systems are attractive building blocks for mechanical metamaterials because their performance is governed by a tunable internal prestress state and can remain robust under geometric and loading variations. In the scope of lattice and metamaterial, recent studies highlighted promising applications in lightweight design, damage-tolerant structures, and tunable systems [1] [2]. This work proposes an optimization-based force-density form-finding framework with tailored geometric and pre-stress constraints to generate super-stable, class-1 tensegrity metamaterials that can tessellate in three dimensions. The resulting metamaterial will be fabricated and tested.

References

[1] Liu, K., Zegard, T., Pratapa, P., & Paulino, G. H. Unraveling tensegrity tessellations for metamaterials with tunable stiffness and bandgaps. *Journal of the Mechanics and Physics of Solids*, 131, 147–166, 2019. doi:10.1016/j.jmps.2019.05.006.

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Speaker



Borui Xu

PhD Student | Princeton University

ID 1004: Enantiomerism and phase transformations in tensegrity structures

2:35 PM – 2:55 PM

Author(s): tarisha moncrief, Tennessee State University; Mohammad hodaei, Tennessee State University; Joshua Jones, Tennessee State University; Anil Misra, Florida International University; Nikhil Admal, University of Illinois, Urbana Champaign; Ranganathan Parthasarathy, Tennessee State University; Youngjae Choi, Tennessee State University

Tensegrity structures gain their structural integrity from a network of pre-tension enclosing discontinuous compression members. The structural design features of tensegrities viz. disjointed compression, and relative compliance of tension members endow them with high impact resilience, active multi-modal mobility control, energy efficiency, and high strength-to-weight ratio compared to traditional structures with continuous chains of compression. Structural instabilities can be engineered into tensegrities exploiting multi-stability, which provides them with the added abilities of shape morphing, rapid actuation, damping, and energy dissipation. This makes multi-stable tensegrity trusses an attractive proposition for a variety of applications including soft robots, structural dampers, crash barriers, and prosthetics. To this end, this research aims to come up with a deterministic approach to engineer multistability in tensegrity structures.

We use a three-pronged approach in our research: (a) Numerical simulation of tensegrities where compression struts are assumed to be perfectly rigid, while tension members follow a rubbery elastomeric behavior, and potential energy minimization is used for form-finding and force-deformation behavior, (b) Experimental proof-of-concept models using wood struts and rubberband tension members to emulate the observed behavior in (a), (c) systematic modification of the structure in both simulation and experiment to achieve and tune the desired multistability.

We first demonstrate that class I tensegrities with prism-type geometries have an unstable equilibrium or potential energy maximum in a flattened configuration. We demonstrate how going through this transition state enables the structure to reorient itself spatially using internal rearrangement of members without rigid body rotations and present the force-deformation curve for this transformation. We find that the structural activation energy to pass through the transition state increases with the number of compression struts.

We then demonstrate how the three-strut simplex can be transformed into a symmetric bipyramid using one additional tension member per node. The bipyramid shows six enantiomeric configurations in simulation. Experimental demonstration of this multistability is underway.

These findings support the development of programmable tensegrity systems and inform the design of adaptive structures and metamaterials that exploit controlled configuration changes to endow structural systems with rapid actuation and damage free energy dissipation.

Speaker



Ranganathan Parthasarathy

Associate Professor | Tennessee State University

ID 537: On the performance of sub-problem solvers for stress-constrained topology optimization using the augmented Lagrangian method

2:55 PM – 3:15 PM

Author(s): Camdon Murphy, University of Missouri; Juan Pablo Giraldo-Isaza, University of Missouri; Oliver Giraldo-Londoño, University of Missouri

Stress-constrained topology optimization (TO) remains a challenging problem, primarily due to the large number of local stress constraints that must be enforced during the optimization process. Recent advances have addressed this challenge through solution strategies based on the augmented Lagrangian (AL) method, in which the original problem is solved as a sequence of bound-constrained minimization sub-problems whose solutions converge to that of the original problem with local stress constraints.

A recent study by Giraldo-Londoño and Paulino [1] presented an educational Matlab code, called PolyStress, which solves the stress-constrained problem via the AL method. PolyStress demonstrated the effectiveness of the method using the Method of Moving Asymptotes (MMA) as the sub-problem solver. However, convergence plots from PolyStress reveal a characteristic behavior in which the objective function (i.e., the volume fraction) converges rapidly and smoothly while the stress constraints exhibit oscillatory convergence near the allowable stress limit. This suggests that the overall performance of the AL framework may depend strongly on the choice of sub-problem solver.

This study presents a comprehensive evaluation of four sub-problem solvers integrated within the AL framework: MMA, Adaptive Moment Estimation (Adam), Limited-memory BFGS with bound constraints (L-BFGS-B), and Sensitivity Separation (SS), the latter having been recently used for multi-material TO [2,3]. Using the PolyStress Matlab environment, these sub-problem solvers were benchmarked on problems designed to expose specific convergence vulnerabilities, including stalling near singular optima, sensitivity to mesh refinement, and instabilities induced by common design criteria. Two small-scale problems, namely the Kirsch three-bar truss and the diagonal square problems, were used to assess performance near singular optima points under varying parameter combinations, while large-scale problems (including the classical L-bracket) were used to examine performance under mesh refinement, the use of linear versus nonlinear material models, and the use of single versus multiple load cases.

The results indicate that the performance of the AL method depends strongly on the sub-problem solver as well as on problem characteristics such as stress singularity type, the type of material model (e.g., linear vs. nonlinear), and loading complexity (e.g., single vs. multiple load cases). The findings also indicate that Adam, L-BFGS-B, and SS may exhibit performance advantages in different design contexts, suggesting that MMA may not always serve as the most effective baseline solver for AL-based stress-constrained TO.

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Speaker



Camdon Murphy

PhD Student | University of Missouri

ID 1040: Bistable origami thermal switch with ultra-high switching ratios

3:15 PM – 3:35 PM

Author(s): Ke Liu, Peking University

Effective thermal management is essential for power electronics that enable AI and robots, highlighting the need for dynamic, reversible thermal switches that facilitate localized control. However, achieving a high switching ratio remains a formidable challenge. Here we create a bistable origami-inspired thermal switch that rapidly toggles between extreme thermal conduction states without requiring external energy or sensory input. Arising from a thin film through precise cut-and-fold, it achieves an unprecedented thermal switching ratio of 13,984 in vacuum and 1,360 in ambient air — orders of magnitude higher than existing solutions. Rapid switching is achieved by snap-through instability, actuated by an intricate combination of thermally responsive shape-memory alloy and elastic springs. The energy landscape of the origami can be programmed through geometric variations to achieve tunable triggering temperature and switching ratio. We demonstrate stable, repeatable thermal regulation across diverse applications, establishing a new paradigm for intelligent passive thermal management.

Speaker



Xiangxin Dang

Postdoctoral Research associate | Princeton University

MS 065: Advanced Computational Methods for Uncertainty Propagation and Risk Assessment in Engineering

2:15 PM – 3:35 PM | Location: GUGG 205

Chair(s): Liyun Xu; Meng-Ze Lyu; Seymour Spence; Jian-Bing Chen; Michael Beer

Moderators



Liyun Xu

Assistant Professor | The University of Texas at Arlington



Meng-Ze Lyu

Research Fellow | Leibniz University Hannover

ID 993: A Probabilistic Digital Twin Framework for Optimal Sensing and Seismic Monitoring of Structural Systems

2:15 PM – 2:35 PM

Author(s): Milad Roohi, University of Nebraska–Lincoln

Conventional seismic SHM often remains decoupled from decision-making, relying on heuristic sensor layouts and offline model calibration. This study bridges this gap by proposing a probabilistic Digital Twin (PDT) framework that unifies optimal sensor placement, nonlinear state estimation, and performance-based engineering (PBE) into a continuous computational workflow. The framework is initialized with an information-theoretically optimal sensing strategy that minimizes response reconstruction uncertainty under sparse instrumentation. This optimized data stream is then coupled with a high-fidelity nonlinear OpenSees model through a probabilistic model-data fusion architecture. An Extended Model-Based Observer (EMBO) serves as the core synchronization engine, leveraging the optimized measurements to enable real-time reconstruction of complete structural states, including unmeasured degrees of freedom and material nonlinearities. The estimated demand parameters are subsequently propagated into a PBE module to quantify decision-relevant metrics, such as damage states, expected economic losses, and re-occupancy suitability. Validated using full-scale seismic response data from the NEESWood Capstone building tests at E-Defense, the framework demonstrates that optimizing sensing configurations for observability significantly enhances the accuracy of real-time nonlinear response reconstruction. This work highlights the role of optimal sensing combined with OpenSees-based state estimation as a scalable pathway toward operational digital twins for post-earthquake decision support.

Speaker



Milad Roohi

Assistant Professor | University of Nebraska-Lincoln

ID 1020: Bayesian Updating of Structural, Nonstructural, and Isolation Parameters of a Base-Isolated Building Using Surrogate Models

2:35 PM – 2:55 PM

Author(s): Kléver Gastón Parra, Engineering and Applied Sciences, Universidad de los Andes, Santiago, Chile; Rodrigo Astroza, Engineering and Applied Sciences, Universidad de los Andes, Santiago, Chile; Saeed Eftekhari Azam, Department of Civil and Environmental Engineering, University of New Hampshire, Durham, NH, USA

Structural health monitoring (SHM) provides information for assessing and managing civil infrastructure under operational and extreme loading conditions. In particular, variations in modal properties are crucial for understanding stiffness degradation, damage progression, and energy dissipation mechanisms. To interpret these effects in civil structures, Bayesian model updating has been widely adopted, using experimental modal properties as calibration targets; however, its application to finite element models of structural systems is often constrained by high computational cost. To overcome this limitation, surrogate models can be employed to efficiently approximate the structural response. In this research, a Bayesian updating framework is presented to estimate structural, nonstructural, and isolation parameters of a base-isolated building through a progressive procedure based on experimental modal properties obtained at different construction stages and during experimental testing. For this purpose, surrogate models are constructed using Polynomial Chaos Expansion (PCE) and are trained and validated to replace a linear finite element model that computes modal properties. First, the elastic modulus corresponding to the most relevant structural elements is estimated considering the bare structure condition using time-invariant modal properties obtained from white-noise base excitation test data. Then, stiffness scaling factors representing nonstructural components are estimated, also using time-invariant modal properties from white-noise tests. Finally, the effective lateral stiffness of the isolation system is estimated using time-varying modal properties identified in short-time windows during seven seismic tests of the fully assembled base-isolated building. Bayesian parameter estimation is performed using a Sequential Monte Carlo (SMC) method. The results show that the proposed approach enables consistent identification of parameters at each experimental stage and accurately captures the evolution of the effective lateral stiffness of the isolation system. The estimated effective stiffness closely matches the effective stiffness reported from the experimental hysteretic analysis, which was computed using the total base shear measured at the shake table platen versus the shear strain of the isolators for each hysteretic cycle.

Speaker



Gaston Parra

PhD Student | University of New Hampshire

ID 764: Community-Scale Hurricane Risk Assessment Considering Wind–Water Interaction

2:55 PM – 3:15 PM

Author(s): Sejin Kim, Chungbuk National University; Liuyun Xu, University of Texas at Arlington; Srinivasan Arunachalam, Verisk; Seymour Spence, University of Michigan; Jeremy Bricker, University of Michigan

Hurricanes impose concurrent wind and storm-surge loads whose interactions can drive building damage and community losses, yet many community risk models still evaluate hazards independently or rely on generalized fragility curves that overlook building-specific geometry and neighborhood proximity. This study proposes a high-fidelity, physics-based community risk assessment framework that couples wind–water loading with component-level damage evolution. A realistic 3D community model is constructed from lidar point clouds and GIS building polygons, while façade features such as windows and doors are identified from street-view imagery to support building-specific demand estimation. Urban wind demands are obtained using an Large Eddy Simulation (LES)-based Computational Fluid Dynamics (CFD) aerodynamic database built for representative wind directions; hurricane time histories of wind speed and direction are then used to synthesize transient wind pressures on each building. Storm surge and inundation are quantified using scenario-specific high-resolution hydrodynamic simulations to compute time-dependent hydrostatic and hydrodynamic actions. Multi-hazard interaction is captured through a time-stepping scheme in which the submerged ratio modulates the relative wind and water contributions, and component failures create openings that update internal pressurization and water ingress, feeding back into subsequent load calculations. Uncertainty is propagated efficiently across hurricane scenarios using enhanced stratified sampling to reduce variance and computational cost while enabling building- and community-level risk metrics. A coastal community case study demonstrates the end-to-end workflow and the importance of explicitly modeling coupled wind–water effects for resilient planning and retrofit prioritization.

Speaker



Sejin Kim

Dr. | Chungbuk National University

ID 1009: Time-Dependent Structural Capacity Models for Performance-Based Design of Floating Offshore Wind Turbine Structures

3:15 PM – 3:35 PM

Author(s): Pawan Chand, New Mexico State University; Doeun Choe, New Mexico State University

Current design practices for floating offshore wind turbine (FOWT) structural components remain predominantly deterministic, despite the presence of complex dynamic behaviors and significant uncertainties that are not yet fully characterized. This study aims to develop time-dependent structural capacity models to support performance-based design of offshore structural components under coupled aero-hydro-servo-elastic dynamics. The time-dependent model accounts for temporal changes in structural capacity, including material fatigue, evolving dynamic behavior and uncertainties arising from marine growth and potential damage. Fragilities estimated using stress-based capacity models defined in terms of normal and shear stresses, as commonly adopted in current offshore industry codes, are compared with those derived from force- and deformation-based capacity models expressed through bending moments, shear forces, and lateral displacements, which are traditionally used in structural design practice. In addition, the relative conservatism of these capacity formulations is systematically assessed. To demonstrate the proposed capacity models, the IEA 15-MW reference wind turbine mounted on a VolturUS-S semisubmersible floating platform is analyzed under U.S. offshore metocean conditions. Uncertainties in environmental loading, structural properties, and modeling parameters are rigorously incorporated within a framework. This research advances offshore wind development by enhancing the understanding of the life-cycle structural performance of floating offshore wind turbine components under coupled aero-hydro-servo-elastic loading, thereby enabling potential reductions in structural mass and improvements in economic competitiveness.

Speaker



Do-Eun Choe

Assistant Professor | New Mexico State University

MS 068: Surrogate Modeling for Uncertainty Quantification, Optimization, and Statistical Inference in Engineering Applications

2:15 PM – 3:35 PM | Location: ECON 119

Chair(s): Alexandros Taflanidis; Bruno Sudret; Abdollah Shafieezadeh; Gaofeng Jia; Min Li

Moderators



Bruno Sudret

Faculty | ETH Zurich

ID 520: An Approach for Reduced-Order Modeling with the Lattice Boltzmann Method for Applications in Wellbore Isolation Fluid Simulations

2:15 PM – 2:35 PM

Author(s): Ali Farahani, University of Pittsburgh; Carlos Garcia, University of Pittsburgh; John Brigham, University of Pittsburgh

The Lattice Boltzmann Method (LBM) is a mesoscopic numerical scheme that propagates particle distribution functions on a discrete lattice through a sequence of collide-and-stream steps. By recovering macroscopic hydrodynamic variables from the moments of these distributions, LBM can effectively estimate complex fluid and solid mechanics behaviors. Due to its inherent locality and strong parallel scalability, LBM is uniquely suited for simulating complex geometries, challenging boundary conditions, and multiphysics or multi-component mechanics. However, despite these advantages, high-fidelity LBM simulations can become computationally prohibitive when applied to many-query workloads, such as inverse analysis, design optimization, and uncertainty quantification for real-world engineering applications. To address this challenge, a data-driven reduced-order modeling framework for LBM is proposed that operates directly in the kinetic distribution-function space. More specifically, this approach projects high-dimensional LBM dynamics onto a low-dimensional subspace, capturing dominant kinetic and hydrodynamic features. Therefore, reconstruction of key parameters, such as velocity and density, is possible with far less computational expense than the traditional (full-order) LBM. Currently, the low-dimensional bases are constructed using proper orthogonal decomposition via the method of snapshots from high-fidelity LBM-generated data. To advance the governing dynamics, a Galerkin-projection formulation is utilized and implemented via a "direct method." This approach is critical as it preserves the intrinsic structure of the underlying collide-and-stream scheme, ensuring consistency with general LBM algorithms. Consequently, this method allows for generalization and enables the implementation of boundary conditions using the exact logic found in full-order LBM solvers. Furthermore, to address the computational bottleneck posed by nonlinear collision terms, the framework incorporates the QR discrete empirical interpolation method as a hyper-reduction technique, ensuring that the efficiency gains of the reduced model are not lost to the cost of expensive nonlinear evaluations. The proposed framework is evaluated against a set of benchmark fluid mechanics problems designed to assess boundary-condition sensitivity, parameter variation, and rheological effects on solution capability. Results demonstrate that the reduced-order modeling approach accurately estimates the mechanics of the systems, while significantly reducing computational expense compared to the full-order LBM. Ultimately, this work seeks to apply the reduced-order modeling strategy to simulate wellbore fluid isolation scenarios, to improve efficiency and effectiveness of the design and evaluation of such systems.

Speaker



Ali M. Farahani

Ph.D Student | University of Pittsburgh

ID 721: Bayesian Deep Learning for Aleatoric and Epistemic Uncertainty Propagation in Nonlinear Structural Dynamics

2:35 PM – 2:55 PM

Author(s): Manisha Sapkota, Department of Civil, Environmental, and Construction Engineering, Texas Tech University; Min Li, Department of Civil and Environmental Engineering, Rensselaer Polytechnic Institute; Bowei Li, Department of Civil, Environmental, and Construction Engineering & National Wind Institute, Texas Tech University

Accurate uncertainty propagation in nonlinear dynamic structural systems is a cornerstone of performance-based engineering and risk-informed decision-making under extreme hazards. While Monte Carlo-based simulation frameworks provide a theoretically sound solution, their reliance on large ensembles of nonlinear time-history analyses renders them computationally intractable. This limitation motivates the development of efficient surrogate modeling strategies that can simultaneously preserve nonlinear system behavior while allowing the quantification of a full range of aleatoric and epistemic uncertainty. This study presents a Bayesian deep learning-enabled metamodeling framework for this purpose. The proposed approach leverages long-short term memory (LSTM) to construct a surrogate mapping between stochastic input processes and full structural response histories, enabling direct estimation of time-dependent responses. Aleatoric uncertainty, including record-to-record variability and system parameter uncertainty (e.g., material properties), is incorporated through structured augmentation of the network input space. Epistemic uncertainty arising from limited training data and training effort is quantified through Monte Carlo dropout that approximates Bayesian inference in a computationally efficient manner. The resulting framework enables rapid generation of response time histories and confidence intervals. Numerical investigations on nonlinear structural dynamic systems were carried out to demonstrate the developed approach. Comparisons with benchmark simulation-based uncertainty propagation approaches indicate substantial gains in computational efficiency, maintain accuracy in probabilistic response estimation, and can simultaneously quantify aleatoric and epistemic uncertainty. The proposed deep learning-based uncertainty propagation framework provides a practical pathway toward scalable probabilistic analysis of nonlinear structural systems. By integrating advanced sequence modeling with principled uncertainty quantification, the approach supports next-generation performance-based assessment, digital twin development, and real-time decision support for structures subjected to uncertain dynamic environments.

Speaker



Bowei Li

Faculty | Texas Tech University

ID 742: A Graph Attention Transformer for Real-Time Economic Dispatch

2:55 PM – 3:15 PM

Author(s): Wenwen Han, University of Southern California; Roger Ghanem, University of Southern California

The increasing penetration of renewable energy resources, coupled with growing load variability and network congestion, has significantly increased the operational complexity of modern power systems. Unit Commitment (UC) and Economic Dispatch (ED) problems must now be solved at high temporal resolution and under stringent physical constraints to ensure reliability and economic efficiency. While traditional mathematical programming approaches provide highly accurate solutions, their computational burden scales poorly with system size, rendering them impractical for near-real-time decision-making in large-scale networks.

This work proposes a novel Spatio-Temporal Graph Attention Transformer (ST-GAT) as a high-fidelity surrogate model for large-scale power system dispatch. The power grid is represented as a dynamic graph in which buses and generators are embedded within the network topology, and transmission lines define spatial connectivity. Spatial correlations induced by network topology and power flows across 186 transmission lines are learned using Graph Attention Networks (GATs), which adaptively weight neighboring nodes to capture congestion-sensitive interactions. Temporal dependencies arising from generator ramping constraints, load fluctuations, and inter-hour operational coupling are modeled using a multi-head Transformer architecture, enabling the learning of long-range temporal patterns over a 365-day horizon involving 327 generators.

To ensure physical consistency and operational feasibility, the proposed model incorporates a physics-informed loss function that explicitly penalizes violations of nodal power balance equations and transmission thermal limits. This hybrid learning framework embeds domain knowledge directly into the training process, reducing physically implausible predictions and improving generalization under stressed operating conditions. The model is trained and evaluated on dispatch solutions generated for the NREL 118-bus system, serving as a realistic benchmark for large-scale power grid operation.

Results demonstrate that the proposed ST-GAT surrogate accurately reproduces generation dispatch patterns and congestion behavior at a fraction of the computational cost required by conventional optimization-based solvers. The model achieves strong predictive performance while maintaining compliance with key physical constraints, highlighting its potential as a real-time decision-support tool. By combining topology-aware graph learning, temporal attention mechanisms, and physics-informed regularization, this work suggests a viable pathway toward autonomous, real-time grid operation and congestion management in next-generation power systems.

Speaker



Wenwen Han

Graduate Student | University of Southern California

ID 824: Functional Generative Neural Operators for Coherent Aleatory and Epistemic Uncertainty Quantification in Flood Forecasting

3:15 PM – 3:35 PM

Author(s): Mehdi Taghizadeh, University of Virginia; Zanko Zandsalimi, University of Virginia; Majid Shafiee-Jood, University of Virginia; Negin Alemazkoor, University of Virginia

Operational flood forecasting must support high-stakes decisions under uncertainty, yet representing uncertainty at the spatial and temporal scales required for actionable impact assessment remains challenging. Physics-based hydraulic models provide high-fidelity inundation dynamics; however, decision-making requires probabilistic forecasts obtained by running many simulations across uncertain forcings, parameters, and initial states (e.g., ensemble sweeps, stochastic forcing, or data assimilation). At high resolution, these ensemble workflows are often computationally prohibitive for real-time use. Data-driven surrogates—such as convolutional models, graph neural networks, and neural operators—therefore enable rapid flood prediction, scenario exploration, and near-real-time decision support at scale.

Uncertainty quantification in learned flood surrogates typically focuses on marginal (pointwise) uncertainty via parametric likelihood heads (e.g., heteroscedastic Gaussian/Laplace regression), quantile regression, or calibration, and represents epistemic uncertainty using approximate Bayesian methods or deep ensembles. While these strategies can improve local reliability, they often struggle to generate field-level probabilistic forecasts that preserve joint spatiotemporal structure, including coherent connectivity, cross-variable consistency, and temporally stable trajectories needed for impact metrics. Diffusion-based generative forecasters can better represent joint structure, but their sampling cost can limit long-horizon rollouts and ensemble size in operational settings.

We propose an uncertainty-aware flood forecasting framework that integrates functional generative uncertainty into a time-dependent geometry-informed neural operator (GINO) surrogate on unstructured meshes. Aleatory uncertainty is modeled through low-dimensional latent variables that stochastically modulate internal network operations (functional noise), yielding distinct yet physically consistent flood evolutions and coherent ensemble members. Epistemic uncertainty is captured through deep ensembles of independently trained operator models. Training uses marginal proper scoring rules (e.g., CRPS) applied pointwise; however, joint spatiotemporal coherence emerges because a shared low-dimensional latent couples predictions across space (and time) within each ensemble member, producing coherent field realizations rather than independent perturbations. The approach is expected to improve probabilistic skill and reliability for flood extent, timing, and connectivity while maintaining deterministic accuracy, enabling efficient uncertainty-aware flood intelligence for emergency management and robust decisions on road closures, evacuations, and resource staging.

Speaker



Mehdi Taghizadeh

Dr. | University of Virginia

MS 074: Innovations in CFD and FSI: Rigorous Methods with Practical Applications

2:15 PM – 3:35 PM | Location: CHEM 140

Chair(s): Yuri Bazilevs; Ming-Chen Hsu; Artem Korobenko; Georgios Moutsanidis; Jinhui Yan

Moderators



George Moutsanidis

Assistant Professor | Rutgers University

ID 585: Study of Salinity Intrusion Mitigation Associated with the Performance of the Augmented Mississippi River Sill (AMRS)

2:15 PM – 2:35 PM

Author(s): Daniel Barreca, ERDC CHL; Ezequiel Martin, ERDC CHL

Salinity intrusion in large river systems during prolonged low-flow conditions is governed by strongly stratified, non-hydrostatic flow processes that are difficult to represent using depth-averaged or hydrostatic modeling approaches. In 2023, an emergency Augmented Mississippi River Sill (AMRS) was deployed in the Mississippi River to arrest the upstream propagation of a saltwater wedge. Although the AMRS was operationally successful, it remains unclear whether the observed mitigation resulted from the sill design itself or from higher-than-anticipated river flows that expelled the wedge before it reached the structure. A rigorous investigation of the governing physics is therefore required to assess and potentially optimize the sill design.

This study presents the development and validation of a fully three-dimensional, non-hydrostatic Reynolds-Averaged Navier–Stokes (RANS) CFD model implemented in OpenFOAM to simulate stratified flow over the AMRS. To address turbulence suppression at the density interface, multiple turbulence model modifications are evaluated. Model performance is assessed using a small-scale demonstration physical model (SDPM) of generic stratified flow interacting with a sill, which provides controlled conditions for evaluating RANS predictions of stratified turbulence and interface dynamics. In addition, large-eddy simulations (LES) are conducted to provide higher-fidelity benchmarks for comparison with the RANS results. As a final validation step, field-scale measurements will be used to assess the accuracy of predicted mean flow and turbulence characteristics.

Speaker



Daniel Barreca
ERDC CHL

ID 615: Recovering accurate wall shear stress in point cloud-based CFD

2:35 PM – 2:55 PM

Author(s): Monu Jaiswal, Iowa State University; Ming-Chen Hsu, Iowa State University

Traditional CFD workflows often encounter significant bottlenecks such as surface reconstruction, geometry cleanup, and boundary-fitted mesh generation, particularly when modeling complex real-world geometries. Point cloud-based CFD offers a transformative alternative by enabling flow analysis directly on discrete points obtained from 3D scanning and imaging. This framework is derived from immersogeometric analysis (IMGA), where the point cloud is immersed into a background mesh, and no-slip boundary conditions are enforced directly on the points through a weak BC formulation based on Nitsche's method. This approach bypasses labor-intensive preprocessing and has proven effective in providing accurate results, including velocity fields, pressure distributions, and total structural loads. Furthermore, the framework has been integrated with photogrammetry to perform direct flow analysis of in-use civil structures. Despite these advantages, accurately predicting local wall shear stress (WSS) remains a critical challenge. In conventional boundary-fitted simulations, accurate WSS estimation relies on strict boundary-layer refinement with consistent wall-normal element heights to ensure smooth velocity gradients. However, in the IMGA framework, the geometry intersects the background grid arbitrarily, resulting in cut elements. This highly unstructured and non-aligned discretization lacks the regularity necessary for consistent gradient calculations, often leading to oscillatory and sub-optimal shear stress predictions. To overcome this limitation, we present a robust stress recovery methodology that ensures accurate, smooth, and physically consistent prediction of WSS while maintaining the inherent flexibility of immersed methodology. We provide extensive validation against benchmark cases and demonstrate the method's efficacy through practical engineering applications.

Speaker



Monu Jaiswal
Graduate Student | Iowa State University

ID 638: Multiscale CFD Analysis Using Divergence-Conforming Truncated Hierarchical B-Splines

2:55 PM – 3:15 PM

Author(s): Kendrick Shepherd, Brigham Young University; Caleb Goates, Brigham Young University

With the increased need for multiscale, multiphysics modeling over geometrically complex domains, there is a pressing need for computational fluid dynamics (CFD) methods that enable higher accuracy for lower computational cost while retaining geometric flexibility and ensuring conservative behavior. These properties are particularly critical for modeling of civil and environmental flow fields, where temporal scales may be long, spatial scales may vary drastically, and accurate modeling of mass conservation plays an important role in environmental simulation.

This presentation will discuss advances in the use of divergence-conforming truncated hierarchical B-splines (THB) in CFD simulation. Spline-based and isogeometric methods have been shown to have higher accuracy per degree of freedom than many traditional finite element methods, and have capacity to natively capture complex and CAD-based geometry. Furthermore, de Rham and divergence-conforming multipatch THB splines ensure amenable properties such as discrete mass conservation while allowing for hierarchical refinement over general domains. Numerical results for both Darcy-Stokes and Navier-Stokes flow will demonstrate both the efficiency and the efficacy of these methods in scalable, high-fidelity simulation.

Speaker



Kendrick Shepherd
Dr. | Brigham Young University

ID 660: A Multiscale Elastohydrodynamic Modeling Framework for Investigating Failure of Wind Turbine Bearings

3:15 PM – 3:35 PM

Author(s): Otero, Spencer Otero, Spencer, Brigham Young University; Kendrick Shepherd, Brigham Young University; Quentin Allen, Brigham Young University

Wind energy plays an increasingly important role in global energy production. However, failure of turbine gearboxes and bearings well in advance of their design life adversely affects the economic costs and reliability of wind-generated electricity. These failures reduce capacity of wind turbines to generate electricity, cost hundreds of millions of dollars, lead to significant downtime, and deter adoption of sustainable energy production tools.

In this work, we are developing a multi-scale physics-based computational bearing lubrication model using the finite element method. The first model of the whole wind turbine, the second is of inside the nacelle, and the last is of the bearing surface. Throughout the different models at different scales, we track the loads through the wind turbine onto the bearings where we calculate pressure and film thickness in the lubrication. A critical component of modeling the multi-scale behavior involves accurate elastohydrodynamic analysis of bearing and gearbox lubrication, which can be modeled using the Reynold's Equation. This work has developed a stabilized dynamic Reynold's equation solver to model bearing surface lubrication.

When the lubrication experiences cavitation, the bearings experience metal to metal contact, which leads to spalling and premature fatigue failure. The main goal of this research is to analyze the effects of adding microtextures to the bearing surfaces. The addition of microtextures to bearing surfaces has significantly decreased fatigue failure in the prosthetics industry. We are investigating the potential that microtextures have in increasing the fatigue life of wind turbine bearings. Microtextures increase the hydrodynamic pressure and load bearing capacity of the lubrication, which in turn should help alleviate fatigue failure.

We have developed an elastohydrodynamic finite element model of the lubrication and bearing surfaces. The elastohydrodynamic model was developed using the Julia finite element library Gridap, [1], [2]. This software was selected because of its rapid compute speeds, its ease of extensibility, and existing functionality for modeling the steady Reynold's equation with variational multiscale functionality, [3], [4]. The existing stabilized Reynold's equation code was used as a steppingstone to a more complex lubrication model. The pressures and film thickness data obtained from the lubrication model feed into the bearing surface model which calculates surface pressure and contact between bearings.

References

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[2] Verdugo, F., and Badia, S. (2022). The software design of Gridap: A finite element package based on the Julia JIT compiler. Computer Physics Communications, 276, 108341.

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[4] Gravenkamp, H., Gridap Reynolds Equation, 2023, doi:10.5281/zenodo.8407785

Speaker



Spencer Otero

Mr | Brigham Young University

MS 078: Wind, surge-wave, flooding and their impacts on infrastructure systems and coastal land

2:15 PM – 3:35 PM | Location: UMC 247

Chair(s): Chao Sun; Celalettin Ozdemir

Moderators



Chao Sun

Associate Professor | Louisiana State University

ID 558: Inlet-Outlet Boundary Conditions for OpenFOAM Multiphase Flow in a U-Bend Channel

2:15 PM – 2:35 PM

Author(s): Khanh Hoang, U.S. Army Engineer Research and Development Center

The US Army Corps of Engineers frequently uses large scale, multiphase, computational fluid dynamic models to assess critical national infrastructure projects including coastal breakwaters, riverine training structures, and hydraulic locks and dams. There are currently various strategies to define the inlet and outlet boundary conditions for multiphase flow, ideally from known parameters such as discharge and tailwater height, to ensure a well-posed numerical problem. To inform best practices and optimize computational efficiency, this study compares numerous methodologies of combined phase, pressure, and velocity fields at the inlet and outlet boundaries in an idealized rectangular U-Bend open channel flume simulated in OpenFOAM. Two inlet boundary conditions for discharge are tested in combination with three outlet conditions holding a constant tailwater. The two inlets allow variable height before computing velocity. The three outlets include the usage of porous media to impose a hydrostatic pressure distribution, a specified hydrostatic pressure distribution from Thorenz, and a split air-water interface with Dirichlet discharge. The results show that the Thorenz inlet and outlet conditions reproduced the discharge and the tailwater height accurately with reduced computational costs. The porous media approach offers reasonable tailwater heights with some error in the discharge. However, this method requires multiple runs to achieve the desired hydrostatic pressure distribution with porosity and has increased runtimes. The discharge discrepancy between the distinct boundary conditions arises from Thorenz's improved interface treatment, which mitigates numerical errors. The Thorenz inlet prevents the accumulation of small phase errors by removing the air-water interface in the velocity calculation. Additionally, the Thorenz outlet applies a Dirichlet discharge during backflow to prevent interface smearing. The study recommends the Thorenz inlet and outlet boundary conditions for simple, computational, multiphase models in OpenFOAM because of effective air-water interface management and minimal computing expenses. These boundary conditions enable more efficient and reliable analysis of hydraulic infrastructures. Further research should focus on the different inlet-outlet boundary conditions in a complex, multiphase case.

Speaker



Khanh Hoang

ORISE Research Fellow | U.S. Army Engineer Research and Development Center

ID 628: Nonlinear Response of Corroded Coastal Bridge Piers Subjected to Extreme Wave Forces

2:35 PM – 2:55 PM

Author(s): Ali Jarrar, University of Delaware; Monique Head, University of Delaware; Alemu Legese, University of Delaware; Shaymaa Obayes, University of Delaware

Coastal bridges in marine environments are increasingly exposed to extreme wave forces during major storm events while simultaneously experiencing long-term deterioration due to corrosion. Although corrosion effects on reinforced concrete bridge columns have been widely documented, their influence on structural response under wave-induced loading remains poorly understood. This study investigates the behavior of corrosion-damaged coastal bridge columns subjected to extreme wave loading conditions. Wave forces are developed from field-based storm data associated with Hurricane Katrina and converted into time-varying hydrodynamic loading using the wave provisions of AASHTO (2008). Corrosion effects are incorporated through published deterioration models that distinguish between atmospheric and splash-tidal exposure zones and are implemented in a nonlinear OpenSEES modeling framework using fiber-based elements to represent varying material degradation along the column height. Before applying the wave loading, the model is checked using a cyclic pushover analysis and compared against laboratory-tested hysteresis data to make sure it captures the expected nonlinear behavior. Preliminary analyses show that nonuniform corrosion along the column height, driven by differences of exposure zones affects the way the column deforms under wave loading, influencing hinge formation, and the locations where damage concentrates. Overall, this work helps improve how the vulnerability of aging coastal bridge piers under extreme wave loading are evaluated.

Speaker



Ali Jarrar

Graduate Research Assistant | University of Delaware

ID 661: Reconstruction of Local Scour Flow Fields Using Generative Adversarial Networks

2:55 PM – 3:15 PM

Author(s): Haq Murad Nazari, Louisiana State University; Celalettin Ozdemir, Louisiana State University; Mayank Tyagi, Louisiana State University

High-fidelity two-phase CFD simulations can generate terabytes of transient, multi-field data per run, creating major bottlenecks in storage, transfer, and downstream analysis. This work investigates whether a generative model can perform temporal super-resolution by synthesizing physically consistent intermediate flow fields between sparsely stored time steps, analogous to frame interpolation used in real-time rendering and video processing. Using a validated Eulerian–Eulerian sediment-transport solver (sedFoam), a database of 7,500 snapshots was collected over 30 s at a sampling interval of 0.004 s on a 128×512 grid. The learning targets are the fluid-phase streamwise velocity and vertical velocity fields.

A conditional generative adversarial network (GAN) is developed in which the generator adopts a U-Net encoder–decoder and is conditioned on spatiotemporal coordinates (x, y, t), enabling inference at intermediate times to generate missing snapshots. The discriminator follows a PatchGAN design to enforce consistency of local flow-field statistics. Training employs a composite objective that combines (i) a pixel-wise reconstruction term, (ii) a gradient-consistency term computed using Sobel operators to penalize derivative mismatches, and (iii) a hinge adversarial loss that drives the generator to match the data distribution of the CFD reference fields. Preliminary results on held-out test snapshots indicate that the model reconstructs velocity fields with root-mean-squared error (RMSE) on the order of $10e-2$ in normalized units, while the largest discrepancies concentrate in the cylinder wake and along the fluid–sediment interface where gradients are strongest. Additional analyses quantify sensitivity to training-data availability across scour-evolution stages following Jensen et al.[1], and show that acceptable reconstruction accuracy ($RMSE \leq 0.05$) can be achieved using only 40–60% of the snapshots, depending on stage. Overall, the proposed GAN framework demonstrates a practical pathway for CFD data reduction, gap-filling of missing snapshots, and future temporal super-resolution in scour simulations

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Speaker



Haq Nazari

Postdoctoral Researcher | Louisiana State University

ID 848: Stochastic framework for assessing structural performance of coastal buildings under tsunami-driven debris impact and damming forces

3:15 PM – 3:35 PM

Author(s): Jayasekara Ravindu Jayasekara, Louisiana State University; Jaril Deschamps, University of Hawai'i at Manoa; Sabarethinam Kameshwar, Louisiana State University; Hyoungsu Park, University of Hawai'i at Manoa

Despite growing experimental and post-disaster evidence, current tsunami structural assessments and fragility models do not accurately incorporate the debris-induced loads and their inherent stochasticity. This omission introduces significant uncertainty into tsunami fragility assessments and risk-based decision-making for coastal infrastructure. To address this gap, this study proposes a probabilistic framework for modeling tsunami-driven debris loads that explicitly accounts for uncertainties associated with debris impact and debris damming effects.

The proposed framework employs the Material Point Method (MPM) to numerically simulate debris transport, impact, and accumulation in front of coastal buildings under tsunami inundation. These simulations enable a statistical characterization of debris–structure interactions that is not feasible with deterministic or purely empirical approaches. The limited understanding of uncertainties in factors such as debris type, the location where debris collides with the structure, and debris velocities before collisions has hindered the inclusion of debris impact loads in existing tsunami fragility assessments. Therefore, first, the framework quantifies the likelihood of debris impacts on a building during tsunami inundation. This will treat debris impact loads as stochastic events within the debris impact model. Furthermore, using simulation results, key uncertain parameters—including debris type, impact location, and pre-impact velocity—are probabilistically defined, enabling their systematic incorporation into structural performance assessments and tsunami fragility analyses. Second, for debris damming, the framework evaluates the spatial distribution of debris accumulation along the width of the building frontage. A previously conducted experimental study provides a modified closure ratio coefficient, expressed as a probabilistic distribution based on site-specific debris availability and flow characteristics, for the design hydrodynamic load equation. However, this coefficient is representative only of the middle column due to limitations of the physical test configuration. Using MPM simulations to quantify the spatial distribution of debris dam formation in front of the building, the experimentally derived closure ratio coefficient is extended to other front-row column locations as well. This results in spatially varying probabilistic distributions of the closure ratio coefficient that account for debris availability, tsunami flow characteristics, and column location across the building frontage.

The proposed framework provides a more realistic and comprehensive representation of debris-induced loading on coastal structures. By integrating probabilistic debris impact occurrence and spatially varying debris damming effects, the framework reduces uncertainty in tsunami fragility assessments and enhances the reliability of structural performance evaluations. These improvements support risk-based design, assessment, and decision-making for coastal infrastructure exposed to tsunami hazards.

Keywords: Structural Assessment, Tsunami, coastal buildings, debris impact forces, debris damming

Speaker



Jayasekara R. Jayasekara

Graduate Student | Louisiana State University

MS 090: 10th Mini-Symposium on 4M (Modeling of Multiphysics, Multiscale, Multifunctional) Engineering Materials and Structures

2:15 PM – 3:35 PM | Location: UMC 415-417

Chair(s): Yong-Rak Kim; Huiming Yin; Chung Song; Jianqiang Wei

Moderators



Chung Song

Professor, University of Nebraska - Lincoln | University of Nebraska

ID 599: Nano-Level Evaluation of Moisture Dependent Strength Degradation of Montmorillonite based on Nano-Indentation and Nano-Scratch Tests

2:15 PM – 2:35 PM

Author(s): Chung Song, University of Nebraska-Lincoln; Dhurba Pandey, University of Nebraska-Lincoln; Elliot Seoh, University of Nebraska-Lincoln; Alexander Silvy, NDOT; Nicholas Glennie, NDOT

Significant strength reduction due to precipitation is commonly observed in surface soils across wide areas of the Midwestern United States. This behavior is analogous to the Rasputitsa condition reported in several European countries. Despite its prevalence and its contribution to safety concerns in many Midwestern states—including Nebraska, Iowa, the Dakotas, Wisconsin, and Kansas—the quantitative mechanisms governing this strength reduction remain insufficiently investigated. This study aims to obtain quantitative insights into soil strength degradation using nanoindentation and nanoscratch testing techniques.

Field soils collected from multiple Midwestern states were examined alongside laboratory-prepared specimens composed of commercially available montmorillonite and kaolinite powders. The clay minerals were wet-mixed at various montmorillonite-to-kaolinite ratios (0, 0.1, 0.2, 0.4, and 0.8) and water contents (10%, 15%, 30%, and 60%). The specimens were oven-dried and subsequently subjected to nanoindentation and scratch tests after curing periods of 0, 1, 2, 4, 8, and 16 days.

From the results, the authors expect that prevalent montmorillonite related fundamental and micro-level geotechnical issues such as slope failure, pavement failure, heaving/sinking of buildings in micro scale level is accurately understood.

Speaker



Dhurba Pandey

Mr. | University of Nebraska-Lincoln

ID 861: Effective mechanical properties of foam concrete transitioning from continuous matrix to cellular microstructure

2:35 PM – 2:55 PM

Author(s): Xinhuan Deng, Columbia University; Byung-Wook Kim, Columbia University; Jinming Zhang, Columbia University; Huiming Yin, Columbia University

This research aims to address the challenge of understanding and predicting the effective mechanical properties of foam concrete with a large range of density caused by introducing different proportions of bubbles, which leads to the microstructure transitioning from voids in a continuous matrix to a lattice-based structure with open cells. The microstructure is characterized with microscopy and effective density; whereas the effective stiffness and strength are measured with cubic samples. For voids in a continuous matrix, classic micromechanics-based models can capture the experimental results well when the porosity is relative low. For cellular microstructure, the recently developed singum model is used to discretize the lattice structure through the Voronoi decomposition, so that the force transfer through the links can be homogenized to predict overall mechanical behavior analytically. There exists a range of porosity (ϕ_l – ϕ_h), where the microstructure can be hybrid without a clear classification for either case. A combination of the classic micromechanical model and the singum model is used, so that the effective stiffness and strength of foam concrete with porosity from 0 to 85% can be predicted. The effect of bubble size is discussed. By incorporating experimentally measured data and material-specific mechanical parameters, the model provides a more robust theoretical and experimental foundation for subsequent investigations of foam concrete with CO₂ curing. Consequently, this research is expected to advance the fundamental understanding of porous material mechanics and to offer a solid theoretical basis for the optimization and design of materials tailored to specific functional requirements.

Speaker



Xinhuan Deng

Mr. | Columbia University

ID 866: Experimental and Multiphysics-based Numerical Investigation of Freeze–Thaw-Induced Microstructural Damage Evolution in Bituminous Composites

2:55 PM – 3:15 PM

Author(s): Nitish Bastola, University of Nebraska-Lincoln; Jamilla Teixeira, University of Nebraska-Lincoln; Chun-Hsing Ho, University of Nebraska-Lincoln

This study investigates critical microstructural changes in bituminous mixtures subjected to moisture-induced damage by freezing–thawing (F–T) cycles. The experimental program integrates laboratory testing with mechanistic numerical simulations. Two bituminous mixtures (SPR1 and SPR2) with different LTC response based on field data were evaluated under controlled F–T conditioning. Initially, specimens were subjected to 0 and 10 F–T cycles based on the AASHTO T 283 standard, followed by LTC semi-circular bending (SCB) tests. Results indicated that after 10 F–T cycles, a noticeable reduction in fracture energy occurred; however, the differences in fracture energy were not statistically significant in distinguishing mixture LTC performance associated with F–T conditioning. Microstructural characterization using X-ray computed tomography revealed a progressive increase in air-void content with F–T conditioning, which is believed to contribute to the observed reduction in fracture energy. Additionally, a testing framework incorporating extended F–T conditioning (90 and 180 cycles) was adopted based on ASTM C666, which can more realistically simulate field conditions, particularly in cold regions, where pavements are subjected to more than 100 F–T cycles annually. This extended conditioning enables a clearer assessment of progressive microstructural degradation and its influence on low-temperature fracture performance. To further investigate these governing mechanisms of LTC, multiphysics-based simulations were performed under varying freeze–thaw cycles and cyclic thermal loading conditions, using phase-field damage model. Modeling results provide a deeper understanding of the LTC behavior of high-RAP mixtures over a wide range of thermal and F-T cycles, extending beyond the practical limitations of laboratory testing.

Speaker



Nitish Bastola

Graduate Research Assistant | University of Nebraska-Lincoln

ID 900: Development of Multifunctional Self-heating Alkali-activated Composites with Biochar and Nano Carbon Black for Bridge Applications

3:15 PM – 3:35 PM

Author(s): In Kyu Jeon, Texas A&M University; Yong-Rak Kim, Texas A&M University

Over 70% of U.S. road mileage lies in snowy regions, making winter roadway safety a persistent national concern. Bridges are especially vulnerable because they cool from both the top and bottom and therefore freeze earlier than the adjacent roadways. Current de-icing practices, including chemical deicers and abrasive applications, are labor-intensive, difficult to apply in real-time, and can accelerate the deterioration of concrete and steel reinforcement. Therefore, developing a sustainable and continuously available de-icing solution that prevents ice formation on the bridge deck and degradation of bridge deck concrete is imperative. As a promising approach to addressing winter traffic safety concerns, a self-heating alkali-activated composite incorporating biochar and nano carbon black system is proposed. This study develops a novel cementitious composite and investigates the effects of biochar and nano carbon black content on the self-heating performance of alkali-activated mixtures through laboratory testing. The optimal contents of biochar and nano carbon black are determined using a Bayesian optimization approach. Experimental results demonstrate the feasibility of a hybrid biochar/nano carbon black system for achieving self-heating performance. Nano carbon black is identified as the dominant factor controlling the self-heating behavior, with a percolation threshold of approximately 3–4 vol% required to initiate significant heating. The optimized mixture exhibited superior self-heating capability at -15°C, achieving a temperature rise above the freezing point within approximately 15 minutes. This study demonstrated the feasibility and proof of concept for integrating biochar and nano carbon black into self-heating alkali-activated composites for bridge infrastructure applications.

Speaker



In Kyu Jeon

Postdoctoral Researcher | Texas A&M University

MS 091: Advances in Modeling of Material Damage and Fracture

2:15 PM – 3:35 PM | Location: UMC 382-384-386

Chair(s): Mostafa Mobasher; Lampros Svolos; Aditya Kumar; Georgios Moutsanidis; Alessandro Fascetti; Ravindra Duddu; Haim Waisman

Moderators



Alessandro Fascetti

Associate Professor | University of Central Florida

ID 339: A Connector–Beam Lattice (CBL) Model for Microscale Mechanical Modeling of Wood

2:15 PM – 2:35 PM

Author(s): Wisdom Akpan, Northwestern University; Erol Lale, Istanbul Technical University; Gianluca Cusatis, Northwestern University

Engineered wood products (EWP) and mass timber systems, such as glued laminated timber (glulam) and cross-laminated timber (CLT), are attracting unprecedented interest in the construction industry due to their favorable structural performance combined with significantly lower CO₂ emissions compared to conventional building materials. However, the heterogeneous and biological nature of wood gives rise to complex mechanical behavior governed by its hierarchical cellular architecture and progressive damage mechanisms, which has historically hindered accurate computational modeling. To address these challenges, the Connector–Beam Lattice Wood (CBL-W) model represents wood as a discrete network of curved beam elements and connectors that directly capture its cellular morphology and explicitly simulate damage and crack evolution at the constituent level through tensile fracture and compression plasticity. The CBL-W model is constructed on anatomically informed, morphology-reproducing microstructures that resolve growth rings, earlywood–latewood transitions, radial cell alignment, and radial rays, yielding a biologically consistent representation of wood at the microscale.

The resulting microscale model predicts elastic response, strength, fracture energy and crack patterns, while requiring minimal species-specific parameter identification. The model is validated through numerical simulations and comparisons with experimental results.

Speaker



Wisdom Akpan

Mr | Northwestern University

ID 408: Coupled Viscoplasticity-Damage Modeling of Metal Alloys Using a Gradient-Enhanced GVIPS Framework

2:35 PM – 2:55 PM

Author(s): Sungwon La, Stanford University; Sina Abrari Vajari, Stanford University; Steven M. Arnold, NASA Glenn Research Center; Christian Linder, Stanford University

Accurate prediction of failure in metal alloys subjected to complex thermo-mechanical loading requires constitutive models that can represent not only viscoplastic deformation but also the initiation and evolution of material degradation leading to fracture. The General Viscoplasticity with Potential Structure (GVIPS) model provides a fully associative, potential-based unified framework for describing the hereditary behavior of materials in the viscoelastic and viscoplastic regimes; however, it does not intrinsically capture damage-induced stiffness degradation nor strength degradation [1,2]. This study develops and investigates a gradient-enhanced damage extension to the existing GVIPS model to enable physically meaningful simulation of damage evolution and failure in metal alloys. The proposed formulation introduces an internal damage variable coupled to the GVIPS free-energy and dissipation potentials, along with a nonlocal gradient regularization that incorporates an intrinsic length scale to prevent mesh-dependent localization and ensure well-posedness of the boundary-value problem. The resulting model captures stiffness degradation, yield strength reduction, softening behavior, and progressive loss of load-carrying capacity while maintaining thermodynamic consistency within the unified GVIPS framework. Material parameters governing reversible deformation, viscoplastic flow, damage initiation, and damage evolution for representative metal alloys are identified through gradient-based minimization of the errors between experimental data and the predicted model response. The extended constitutive model is implemented in a finite-element framework and applied to simulate various loading scenarios to evaluate its ability to predict strain localization, damage accumulation, and failure modes. This work establishes a robust and extensible modeling framework for coupling viscoplasticity and damage within GVIPS and provides a foundation for predictive simulation of failure in advanced metal alloys under extreme service conditions.

[1] Saleeb, A. F., & Arnold, S. M. (2001). A General Time Dependent Constitutive Model: Part I—Theoretical Developments. *J. Eng. Mater. Technol.*, 123(1), 51-64.

[2] Saleeb, A. F., Arnold, S. M., Castelli, M. G., Wilt, T. E., & Graf, W. (2001). A general hereditary multimechanism-based deformation model with application to the viscoelastoplastic response of titanium alloys. *International Journal of Plasticity*, 17(10), 1305-1350.

Speaker



Sungwon La

PhD Candidate | Stanford University

ID 421: Effect of Particle Shape on the Fracture Toughness of Particle-Based Materials

2:55 PM – 3:15 PM

Author(s): Shahlaa Al Wakeel, Saint Martin's University

The reliability of any structure is a function of its resistance to fracture. In particle-based materials, such as concrete, it is strongly governed by its heterogeneous microstructure and inherent flaws that lead to stress concentration and crack initiation [1]. The existence of cracks and flaws decreases the material strength, and it continuously weakens the material until it cannot carry any more load, and a fracture arises [2].

To design a material microstructure for crack control, there is a need to consider the particle shape effect on the material's fracture toughness. This research aims to address the effect of particle shape within the particle-based heterogeneous materials on their fracture toughness. Particle morphology plays a vital role in governing local stress fields in front of the crack tip and the energy release rate during fracture. Thereby influencing crack initiation, propagation, and overall fracture resistance [3]. However, this effect is missing from current fracture formulations.

Understanding the effect of particle shape in heterogeneous materials, it is possible to reduce stress concentration within the material during loading. The research focuses on quantifying the variation in fracture toughness induced by particle morphology by incorporating three-dimensional particle shapes into both theoretical and experimental analyses. A general relationship between plane strain mode I fracture and particle shape is derived within the framework of Linear Elastic Fracture Mechanics (LEFM). The investigation is carried out by using standard single-edge notched beam specimens subjected to a three-point bending test. Finite element simulation is used to evaluate the fracture toughness of particles with different morphologies.

Understanding how the particle morphology embedded in the matrix affects the stress field in front of the crack tip and the energy release rate during fracture will provide a better understanding of how to engineer the material to enhance fracture resistance.

[1] Baz`ant ZP, Planas J. 1998. Fracture and size effect in concrete and other quasibrittle materials. Boca Raton, FL: CRC Press. pp. 7-22.

[2] Gross D., Seelig T. 2006. Fracture mechanics with an introduction to micromechanics. Springer-Verlag Berlin Heidelberg. pp. 218-287.

Speaker



Shahlaa Al Wakeel

Assistant Professor | Saint Martin's University

ID 627: Innovative Design Tools to Efficiently Analyze Cracking in Concrete Structures

3:15 PM – 3:35 PM

Author(s): William Orben, Simpson Gumpertz & Heger; Colin Allen, Simpson Gumpertz & Heger; Ethan Pennywitt, Simpson Gumpertz & Heger

The assessment of structural systems under high-temperature loading is a historically expensive computational task and relies heavily on assumptions regarding structural behavior. The self-relieving nature of concrete under tensile stress is a critical consideration when assessing the strength of any concrete component; after all, concrete cracks. However, the need for more robust thermal analysis methods is evident as the market for continuously operational structures, such as nuclear facilities, industrial facilities, and data centers, continues to grow.

This session will explore the theoretical and computational limitations in the current assessment of concrete building and non-building structures under high-temperature loading and propose innovative methods for the thermal analysis of such systems. These methods aim to provide realistic structural behavior without the need for time-intensive nonlinear analyses, resulting in more efficient and economic design and repair solutions.

Boundary conditions, component geometry, the magnitude of heat flux, and dynamic material properties lead to complexity in assessing structural safety during accidental thermal changes. Although the magnitude of the temperature is relatively low, large-scale effects and the considerations listed above can cause these thermal loads to significantly influence the design of a concrete component, especially when combined with seismic, wind, and gravity loading. The analysis of combined structural systems exacerbates the challenge of confidently considering these variables in structural design and assessment.

The objective of this session is to offer an accessible and controlled approach to assessing the non-linear performance of concrete structural systems exposed to high-temperature loading, while fostering discussions on dynamic material properties and widely accepted engineering assumptions. We aim to enhance the understanding of how structures respond to thermal stress and invite contributions that highlight research and development of various design codes for assessing the behavior of concrete under thermal-induced stress.

Speaker



William Orben

Associate Project Consultant | Simpson Gumpertz & Heger

MS 094: Mechanics and Physics of Granular Materials

2:15 PM – 3:35 PM | Location: VAC 1B20

Chair(s): Ryan Hurley; Marcial Gonzalez; Yimin Lu; Dawa Seo; Alessandro Rotta Loria; Ali Daouadji

Moderators



Ryan Hurley

Associate Professor | Johns Hopkins University

ID 391: Dynamic Characterization of Ballast Mechanical Properties Post-Tamping Maintenance

2:15 PM – 2:35 PM

Author(s): Ahmed El Saei, Southern Methodist University; Usama El Shamy, Southern Methodist University

Effective railway maintenance relies on tamping and Dynamic Track Stabilization (DTS); however, the internal mechanical response of ballast subjected to these high-energy processes is difficult to measure directly in the field. This study develops a high-fidelity Discrete Element Method (DEM) framework to simulate ballast maintenance, including tamping and subsequent DTS loading. An approach is further proposed to estimate the strain-dependent ballast shear modulus, G , using measurements obtained during DTS simulations.

To capture the mechanical complexity, interlocking, and angularity of the ballast layer without the computational expense of explicitly modeling particle geometries, a linear contact model augmented with rolling resistance was adopted. Model verification was performed using multiple benchmarks. Angle of repose tests were conducted to assess particle-scale interlocking behavior; dynamic excitation tests were used to estimate the small-strain shear modulus, $G_{\max}$; and pre- and post-tamping lateral resistance tests were carried out, with layer-scale responses compared against field measurements.

Dynamic excitation tests with varying amplitudes were then applied to induce a range of shear strains and characterize the ballast layer response. From these simulations, strain-dependent shear modulus reduction ($G/G_{\max}$) and damping curves were derived. The ballast deposit was subsequently subjected to simulated tamping to quantify compaction and evaluate changes in mechanical behavior.

A key contribution of this work is the estimation of strain-dependent shear modulus and damping during DTS motion. The evolving shear modulus during DTS is correlated with the shear modulus reduction curve obtained from independent dynamic excitation tests. The resulting shear modulus estimates fall within realistic ranges for both loose and compacted ballast, demonstrating the capability of the proposed workflow. When combined with process-level DEM simulations, this approach shows strong potential for improving predictions of tamping performance and supporting the optimization of maintenance parameters for granular railway foundations using DTS.

Keywords

Railway maintenance, tamping, dynamic track stabilizing (DTS), discrete element method (DEM), ballast bed resistance, granular material, vibration dynamics

Speaker



Ahmed El saei

Ph.D. Student | Southern Methodist University (SMU)

ID 417: Scaling discrepancy on the screening of elongated and plate-shaped biomass particles

2:35 PM – 2:55 PM

Author(s): Weihe Sun, Texas Tech University; Yidong Xia, Idaho National Laboratory; Jordan Klinger, Idaho National Laboratory; Yimin Lu, Texas Tech University

Effective separation and grading of biomass feedstocks are critical to bioenergy supply chains and directly govern the efficiency of downstream conversion processes. However, the unique geometric characteristics and material properties of milled biomass particles bring significant challenges for smooth industrial screening. For example, the screening behavior observed at laboratory scale may not apply to the industrial scale, and the current screening operations heavily rely on trial-and-error and engineering experiences, which lead to significant time and economical costs. To solve the scaling discrepancy issue with generalizable mechanistic understanding, this study investigates the screening behavior of milled miscanthus at both bench-scale circular laboratory sieves and pilot-scale orbital screens using discrete element method (DEM) simulations.

We employed polyhedral-shaped particles with different aspect ratios to capture the elongated and plate-shaped feature of the material, with relatively simple Hertz-Mindlin contact model. Simulations were performed to simulate the screening at both bench-scale (a cylinder with 20-cm diameter) and pilot-scale (a 120 × 50 cm² rectangle) equipment. Each simulation is monodispersed in order to decouple the mixing effects among different particle sizes.

The results show that, while the bench-scale system maintained near-perfect efficiency (>95%) for narrow particles (widths of 1.2–2.4 mm) regardless of length (up to 40 mm), the pilot-scale system exhibited acute sensitivity to length, with efficiency dropping to 30% as length approached 40 mm. This constraint was further intensified for wider particles (7.2 mm), where the critical passing length contracted from 18 mm at the bench scale to 12 mm at the pilot scale. Particle-scale analysis identifies particle orientation—rather than bulk kinetic energy or agitation intensity—as the most critical factor governing the scaling discrepancy. Although both screening systems exhibited comparable particle velocity and elevation distributions, the pilot-scale flow confined approximately 90% of particles to a "flat" orientation (<20° relative to the deck). In contrast, the bench-scale system, influenced by dominant boundary wall effects, promoted vertical tilting (90% of particles between 20°–50°), which facilitated unrepresentative passage. These findings demonstrate that the physical scale of the screening system fundamentally alters screening efficiency, providing a mechanistic basis for correcting bench-to-pilot deviations and establishing a theoretical foundation for reliable scaling laws in biomass preprocessing infrastructure.

Speaker



Weihe Sun

PHD Student | Texas Tech University

ID 418: Granular deposition by dry pluviation: a discrete element study on segregation and packing mechanics

2:55 PM – 3:15 PM

Author(s): Jimin Park, Yonsei University; Dawa Seo, Wayne State University; Tae Sup Yun, Yonsei University

Granular materials constitute the fundamental components of various geotechnical systems, including slopes, drainage layers, and embankments. Understanding and management of granular systems is related to key properties such as mechanical stability and hydraulic conductivity, which require a characterization of inherent uncertainties from segregation. Segregation leads to spatially nonuniform particle arrangements, which resulting in heterogeneity and anisotropy in mechanical and hydraulic responses.

Dry pluviation is commonly employed in both laboratory testing and field-scale construction, where granular particles are allowed to fall freely under gravity to form sediment layers. Numerous experimental and numerical studies have investigated the behaviors of pluviated deposits, reporting macroscopic characteristics such as angle of repose and bulk porosity. Experimental observations have also explored the occurrence of segregation under various particle size distributions and depositional conditions. While bulk-scale behaviors and surface-level segregation patterns have been identified through laboratory testing, resolving the internal structures of the deposit and the segregation mechanisms remains challenging. In addition, despite recent advances in image-based analysis techniques that have enabled efficient identification of depositional patterns, these approaches provide only indirect insight into internal segregation process due to their reliance on surface visibility. To overcome these limitations, numerical approaches capable of resolving particle-scale interactions are required.

In this study, the discrete element method (DEM) is employed to simulate the dry pluviation of sand with varying particle shapes and grain-size distributions. The DEM model is rigorously calibrated using experimental reference data to ensure realistic representation of both particle-scale interactions and macroscopic responses. Following the validation, a series of parametric simulations is conducted by varying particle shape, grain-size distribution, and particle orientation, to examine their influence on depositional behavior. Macroscopic indicators such as angle of repose are evaluated alongside detailed analyses of spatial segregation and internal stacking structures such as local porosity and segregation index.

The results provide comprehensive insight into how particle shape, size distribution, and deposition conditions influence packing configurations and segregation patterns. These findings contribute to a deeper understanding of granular deposit formation and management of uncertainty in geotechnical applications.

Speaker



Dawa Seo

Dr. | Wayne State University

ID 512: Entangled granular materials: Designing particles with barbs and hooks to maximize tensile strength

3:15 PM – 3:35 PM

Author(s): Youhan Sohn, University of Colorado Boulder; Saeed Pezeshki, University of Colorado Boulder; Francois Barthelat, University of Colorado Boulder

Entangled granular matter offers interesting perspectives in terms of assembly, disassembly and mechanical performance. The intrinsic reversibility of entanglement allows for fully recyclable materials and structures, providing a sustainable alternative to permanent bonding. However, short and long range entanglement mechanisms remain poorly understood. Here we propose a simple pick-up experiment to measure entanglement in staple-like particles with varying leg lengths, crown-leg angles, and backbone thicknesses. We also introduce a "throw-bounce-tangle" model based on a three-dimensional geometrical entanglement criterion between a pair of staples, along with a Monte Carlo simulation to predict entanglement probabilities in staple bundles. This framework integrates stochastic collision with rigorous geometric exclusion criteria, effectively capturing the transition from a loose packing state to a rigid entangled network. This computationally efficient model predicts an average entanglement density consistent with experimental measurements. We then extend this model and experiments to more complex particles made of multiple branches and barbs. Specifically, we use the model to identify the optimal number of branches, which results in entanglement strengths several times greater than simple staples. We attribute this enhancement to the cooperative interlocking of multiple planar branches, which creates robust percolation networks that resist tensile failure. Collectively, these new designs for tunable "entangled granular metamaterials" offer a unique combination of strength, extensibility, and toughness that may soon outperform lightweight engineering materials like solid foams and lattices, opening new avenues for developing reversible, impact-resistant structures in soft robotics and civil engineering.

This work was supported by the US National Science Foundation (Mechanics and Materials and Structures, Award No. 2033991 and No. 2517927).

Speaker



Youhan Sohn

University of Colorado Boulder

MS 041: Cementitious Materials: Experiments and Modeling Across the Scales

2:15 PM – 3:35 PM | Location: HUMN 1B80

Chair(s): Bernhard Pichler; Gilles Pijaudier-Cabot; Günther Meschke; Christian Hellmich; Franz Josef Ulm

Moderators



Gilles Pijaudier-Cabot

Université De Pau Et Des Pays De L'adour

ID 1035: Characterization of a Cracked RC Beam using Synthetic Aperture Radar Imaging and the K-R-I Transform

2:15 PM – 2:35 PM

Author(s): Tzuyang Yu, University of Massachusetts Lowell

Portland cement concrete (PCC) structures (reinforced and prestressed) are most widely used in civil infrastructure systems such as bridges, buildings, tunnels, roadways, waterways, dams/levees, and nuclear power plants. In many cases, PCC is the only available engineering material to use to achieve a design lifespan of 50 to 75 years. During the lifespan of concrete structures, cracking of concrete occurs due to various reasons including poor quality control, over-stressing, steel corrosion, carbonation, and alkali-aggregate reaction. In any case, the structural severity of a concrete crack must be assessed to determine its impact on the safety and sustainability of concrete structures. However, due to the brittle nature of PCC, generation of real cracks in concrete structures is a challenging task in terms of controlling crack width, crack length, and crack depth. The objective of this paper is to apply synthetic aperture radar (SAR) imaging on a cracked laboratory reinforced concrete (RC) beam to remotely detect and characterize the presence and severity of hair cracks on the RC beam. A water-to-cement (w/c) ratio of 0.4 was used in casting the beam. 28 days of curing were applied to the RC beam, before another month of room drying. A four-point bending test was applied to the RC beam to generate cracks of different sizes from hair cracks to large cracks. The RC beam was subjected to a laboratory SAR imaging system using 10.5 GHz continuous waves at different ranges. The backprojection algorithm was used in processing reflected continuous waves to reconstruct spatial images of the RC beam inside an electromagnetic anechoic chamber (1-18 GHz). Experimentally collected SAR images were processed by the K-R-I transform to generate 3D K-R-I curves for comparison. From our result, it is found that SAR imaging and the K-R-I transform can remotely detect and reconstruct the scattering pattern of surface and subsurface cracks.

Speaker



Tzuyang Yu

Professor | University of Massachusetts Lowell

ID 206: Differentiable Physics-Informed Learning for Multi-Scale Design of Fiber-Reinforced Cementitious Composites: From Micromechanics to Macroscopic Optimization

2:35 PM – 2:55 PM

Author(s): Jiawei ZHONG, The Hong Kong University of Science and Technology

The design of High-Performance Fiber-Reinforced Cementitious Composites (HPFRCC) is traditionally hindered by the high-dimensional, non-linear relationship between mix composition, interfacial micromechanics, and macroscopic structural performance. While pure data-driven algorithms offer predictive capabilities, they often lack physical interpretability, require prohibitive amounts of training data, and struggle to generalize outside the training domain. To address these limitations, this study proposes a differentiable physics "gray-box" framework that seamlessly integrates deep learning with analytical micromechanics to bridge the gap between material chemistry and structural performance.

We introduce a hybrid experimental-computational framework that couples systematic single-fiber pull-out experiments with differentiable physics-informed learning. At the microscale, we experimentally characterize fiber-matrix interfaces through controlled pull-out tests, normalizing for geometric variability to isolate intrinsic material behavior. These data train a physics-constrained neural architecture comprising two distinct pathways. First, a material encoder predicts fundamental interfacial parameters, specifically initial frictional bond strength τ_0 , chemical bonding energy G_d , slip-hardening coefficient β , and snubbing coefficient f , directly from mix proportions. Second, a differentiable physical decoder implementing analytical single fiber pull-out relationship. Crucially, a parallel residual network compensates for unmodeled experimental phenomena (such as matrix spalling or fiber surface abrasion), ensuring thermodynamic consistency while capturing complex behaviors that simplified analytical solutions miss.

Because the analytical equations are implemented as differentiable layers, gradients can propagate through the physical model. This enables two critical inverse workflows. First, in inverse characterization, the model accurately retrieves interfacial bond parameters from mix proportions, significantly outperforming purely data-driven baselines in low-data regimes. Second, in inverse design, we utilize the differentiable nature of the physics layer to perform gradient-based optimization of the inputs. This allows for the automated discovery of optimal binder ratios and fiber geometries that maximize specific mechanical objectives.

To bridge the scale gap, micromechanical predictions are upscaled to macroscopic tensile toughness via probabilistic homogenization, which integrates the single-fiber pull-out work over probability density functions representing fiber orientation and embedment length. Experimental validation across multiple distinct mix designs demonstrates that our approach outperforms purely empirical models in predictive accuracy while maintaining physical interpretability. By enabling the rapid, computational exploration of the material design space, this framework provides a robust tool for designing sustainable cementitious materials, reducing reliance on trial-and-error experimentation and facilitating the optimization of low-carbon binder systems for high-ductility infrastructure.

Speaker



Jiawei Zhong

Student | The Hong Kong University of Science and Technology

ID 514: Next-Generation Concrete Reinforcement: The Case for Auxetic and Non-auxetic Steel Lattices.

2:55 PM – 3:15 PM

Author(s): Neeraj Sharma, Indian Institute of Technology (BHU); Kshitij Kumar Yadav, Indian Institute of Technology (BHU)

Recent advancements in additive manufacturing have positioned architected mechanical metamaterials at the forefront of materials research; however, their practical application in structural engineering remains limited. This study investigates the mechanical behavior of concrete reinforced with architected steel lattices, comparing auxetic (negative Poisson's ratio, NPR) and non-auxetic (Poisson's ratio > 0) geometries. Through uniaxial compression testing, the influence of lattice orientation and cell size on the composite's performance was evaluated. The results demonstrate that auxetic lattices provide an "active confinement" effect. Specifically, the NPR characteristics counteract lateral expansion under axial load, leading to a significant enhancement in both the ultimate strength and ductility of the concrete members. Conversely, non-auxetic lattices, despite their high inherent stiffness, resulted in higher compressibility and less effective reinforcement due to a lack of lateral confinement. These findings suggest that architected auxetic reinforcements offer a promising pathway for developing high-performance, ductile structural components.

Speaker



Neeraj Sharma

Ph.D candidate | Indian institute of technology (BHU) Varanasi

ID 947: Impact of loading rate on dynamic response of aged concrete

3:15 PM – 3:35 PM

Author(s): Sannidhya Ghosh, DCI Engineers; Mija Hubler, University of Colorado Boulder; Petros Sideris, Texas A&M University

In seismic performance analysis of existing and the design of new reinforced concrete structures, the impact of aging considerations is neglected. This is a study of the effect of long-term creep of concrete under various aging durations on the loading rate or strain rate sensitivity and seismic response of concrete structures. The rate sensitivity of compression strength and modulus of elasticity of concrete are studied on accelerated aged samples. Samples are accelerated aged under the combined effect of heat and service load. This study further intends to understand how combined mechanical and thermal loading further accelerates the aging process of concrete and impacts its mechanical properties, such as modulus of elasticity, splitting tensile strength, and fracture energy. Samples were initially cured under ambient laboratory condition before being accelerated aged to their respective target equivalent ages in a heat chamber. Both sample sets were exposed to the same elevated temperature under a constant compression load of 27.5% of their 28-day strength for their respective required number of days. Once the samples reached their desired equivalent age, they were loaded in compression under different strain rates, representative of earthquake ground accelerations, until failure. It was found that the compressive strength and modulus of elasticity of younger concrete are more sensitive to strain rate as compared to older concrete, and the younger concrete is much stronger and more elastic under higher strain rates than older concrete. The results also show that the Dynamic Impact Factor proposed by the CEB is an overestimation of concrete strength at high strain rates. This study provides insight into the effect of aging on the loading rate effect of concrete to better understand the seismic response of aged concrete structures. This will help make modifications in structural design to make concrete structures seismic resilient even at older ages.

Keywords: accelerated aging, seismic performance of concrete, maturity method, concrete creep

Speaker



Sannidhya Ghosh

Structural Project Engineer | DCI Engineers

Coffee Break

3:35 PM – 4:00 PM | Location: UMC - Aspen Rooms & UMC - 235

MS 075: Wildfire Impacts and Resilience in WUI Communities: From Field Data to AI-Driven Future Planning

4:00 PM – 6:00 PM | Location: HUMN 250

Chair(s): Serdar Selamet; Ertugrul Taciroglu; Negar Elhami-Khorasani; Sriram Narasimhan; Erica Fischer

Moderators



Serdar Selamet

Managing Engineer Consultant | Exponent Inc.

ID 298: A Multi-Level Framework for Modeling Wildfires in a Wildland-Urban Interface: Case Study of the 2025 Eaton Fire

4:00 PM – 4:20 PM

Author(s): Tanmay Vora, University of Michigan; Seymour Spence, University of Michigan; Ann Jeffers, University of Michigan

The recent Eaton and Palisades fires caused the destruction of over 15,000 structures, according to the California Department of Forestry and Fire Protection. Predicting fire spread in communities located in the wildland-urban interface (WUI) includes modeling fire spread in the wildland, at the interface, and inside the urban domain. Fire propagates through three mechanisms: flame convection, thermal radiation, and firebrand spotting. Firebrands are burning embers ejected from a fire front. Community-scale wildfire models neglect or make simplifying assumptions for these processes. Computational fluid dynamics (CFD)-based approaches provide high-fidelity results but suffer from high computational expense. A multi-level framework is proposed to overcome the limitations of current wildfire models and provide an accurate estimate of fire spread inside communities located in the WUI. This framework divides the WUI in four domains: wildland, transition, urban, and communities of interest. The transition domain is the vegetation surrounding the urban domain. Fire spread in the wildland domain is modeled due to convection, whereas in the transition domain it is modeled due to convection and spotting. In the urban domain and the communities-of-interest domain, fire spread due to radiation and spotting is modeled. Different distributions of firebrand mass and size are considered for structures and vegetation based on experimental and field data. Fire spread in communities of interest is modeled using a CFD-based Euler-Euler multiphase approach, where the wind-driven fire can be modeled using unsteady Reynolds-averaged Navier-Stokes (URANS) or large eddy simulations (LES) approaches. In this domain, firebrands are modeled explicitly using a continuum formulation and treated as multiple interpenetrating fluid phases. In the other three domains, a coupled Weather Research and Forecasting (WRF)-Fire with Streamlined Wildland-Urban Interface Fire Tracing (SWUIFT) model is used to simulate fire spread. WRF-Fire models fire spread due to convection while SWUIFT models the radiation and spotting components. WRF-Fire uses a level-set algorithm to propagate the fire front along with Rothermel's rate-of-spread model, while SWUIFT uses simplified probabilistic distributions to model firebrand transport and models radiation only for buildings. The wind flow in these domains can be simulated using WRF-ARW (Advanced Research WRF) or WRF-LES models, depending on the required fidelity. These models provide time-varying boundary conditions for the CFD domain, which are very important to obtain accurate results. The Eaton fire is recreated using this approach, and the structural ignition timelines are validated against reported values. This multi-level approach provides a first step towards high-fidelity WUI fire spread models while being computationally fast enough to provide real-time results. These results can provide valuable information regarding firefighting, evacuation, and designing wildfire-resilient communities.

Speaker



Seymour Spence

Associate Professor | University of Michigan

ID 409: Automating Building-Level Fire Damage Classification with AI Using UW RAPID Post-Disaster Imagery

4:20 PM – 4:40 PM

Author(s): Barbaros Cetiner, University of Washington, RAPID Facility; University of California, Berkeley; Jeffrey Berman, University of Washington, RAPID Facility; Karen Dedinsky, University of Washington, RAPID Facility; Jaqueline Zdebski, University of Washington, RAPID Facility; Joseph Wartman, University of Washington, RAPID Facility

As wildfire and urban fire incidents increase in frequency and severity, engineers, scientists, and policymakers need faster ways to convert large volumes of post-disaster imagery into actionable insights on structural performance and damage patterns. Hence, tools that automate fire-damage prediction from image data are becoming increasingly critical for enabling prompt, uniform, and scalable post-event assessment of the built environment. The open-source rAPIdtools Python package, developed by the RAPID facility at the University of Washington, addresses this need by providing a state-of-the-art workflow for automating fire-damage classification from multi-modal post-disaster imagery.

Leveraging post-disaster image data collected by the RAPID facility, rAPIdtools enables repeatable, end-to-end automation that can be deployed across large spatial extents with minimal manual intervention. rAPIdtools is equipped with multiple adaptable approaches to extract nadir building imagery from aerial imagery and multi-angle building imagery from street-level and oblique imagery in a fully automated manner, offering an extremely efficient way to sift through large datasets of imagery for the purposes of building damage evaluation. For fire-damage assessment, rAPIdtools integrates multiple customizable computer vision and large language model components to quantify damage in metrics that can be aligned with a broad range of objectives. Together, these capabilities substantially reduce the time and manual effort required to identify, curate, and analyze damage-relevant views across large imagery collections.

This presentation provides an overview of rAPIdtools' current and planned damage-classification capabilities. It also presents an in-depth evaluation of its damage-quantification workflow using datasets collected by the RAPID Facility, in collaboration with other NSF-supported researchers, from the 2025 Palisades and Eaton fires through benchmarking automated classifications against manually curated ground-truth labels. Results indicate that AI-based image analysis performed using rAPIdtools can accurately quantify building damage distributions at scale as well as substantially reduce the time, cost, and safety risks associated with post-fire reconnaissance compared with traditional methods.

The final part of this presentation explores the practical applications of the rAPIdtools framework, specifically in advancing performance-based fire engineering and conducting community-scale resilience analyses for fire-borne hazards. By reducing technical barriers to integrating AI into post-disaster workflows, rAPIdtools aims to facilitate reproducible research and data-driven improvements in fire-resilient design and mitigation. This presentation provides empirical evidence demonstrating this potential via a data-driven evaluation of rAPIdTools' efficacy in classifying fire damage.

Speaker



Barbaros Cetiner

Software Developer | University of California, Berkeley

ID 434: Statewide Road Network–Specific Wildfire Risk Profiling Using Accelerated Fire Spread Models

4:40 PM – 5:00 PM

Author(s): Binita Dahal, Colorado State University; Debasish Jana, Colorado State University

Wildfire risk assessments are increasingly used to inform mitigation and planning decisions at the state scale; however, existing studies predominantly characterize wildfire hazard over continuous landscapes, with limited attention to how risk manifests specifically across transportation networks. As road networks are critical for evacuation, emergency response, and post-fire recovery, understanding their exposure and vulnerability to wildfire requires network-aware modeling frameworks that go beyond aggregate, state-level risk maps.

In this study, we develop a state-wide, road network–specific wildfire risk profile by integrating high-resolution wildfire spread simulations with spatially embedded road infrastructure. We employ PyTorchFire [1], a GPU-accelerated wildfire simulator to efficiently generate large ensembles of wildfire spread scenarios under varying ignition, fuel, weather, and topographic conditions. The accelerated framework enables rapid exploration of uncertainty and fine-scale fire–road interactions that are computationally prohibitive with traditional simulators. Model outputs are validated against FARSITE [2] simulations to ensure physical consistency in fire growth patterns and spread dynamics.

We quantify wildfire risk along road networks using metrics that capture burn probability, exposure frequency, and spatial clustering of high-risk road segments, and compare these results against conventional state-level wildfire risk representations. Our findings demonstrate that road network wildfire risk exhibits strong spatial heterogeneity that is not reflected in aggregated landscape-based assessments. In particular, critical road corridors and connectivity bottlenecks experience disproportionately high wildfire exposure despite being located in regions of moderate overall wildfire risk.

The proposed framework highlights the importance of infrastructure-specific wildfire risk analysis and provides a scalable, physics-informed approach for transportation agencies and emergency planners to prioritize mitigation, monitoring, and resilience investments at the network level.

[1] Xia, Z. and Cheng, S., 2025. PyTorchFire: A GPU-accelerated wildfire simulator with Differentiable Cellular Automata. *Environmental Modelling & Software*, 188, p.106401.

[2] Finney, M.A., 1998. FARSITE, Fire Area Simulator–model development and evaluation (No. 4). The Station.

Speaker



Binita Dahal

Graduate Student | Colorado State University

ID 594: WUIgniS: A Physics-Informed and Inference-Guided Numerical Ignition Simulator for Wildland-Urban Interface Fire Spread

5:00 PM – 5:20 PM

Author(s): Devasmit Dutta, University of California, Los Angeles (UCLA); Patrick Nicholas Hadinata, University of California, Los Angeles (UCLA); Riyaz Shaik, University of California, Los Angeles (UCLA); Ertugrul Taciroglu, University of California, Los Angeles (UCLA)

In recent years, wildfires reaching the wildland-urban interface (WUI) fires posed an escalating risk to communities due to extreme weather and climate-driven fuel variability. Researchers worldwide are developing models to predict WUI fire spread rate and direction; each existing model has inherent limitations. This study presents WUIgniS, a high-resolution, physics-informed numerical ignition and fire spread modeling framework designed for community-scale WUI risk assessment that overcomes the limitation of direct flame contact representation present in many existing models. The framework couples a cellular-automata core with semi-physical ignition mechanisms, including thermal radiation, direct flame contact, and wind-driven firebrand spotting, while ingesting heterogeneous urban and vegetative fuel representations. To enable realistic representation of large-scale fire evolution and atmospheric forcing, WUIgniS is driven through an offline, one-way coupling with mesoscale fire-atmosphere simulations. Outputs from a WRF-based wildfire model provide time-resolved wild-land fire positions and high-resolution surface wind fields, which serve as dynamic inputs for community-scale ignition and spread simulations, allowing wind-gust variability to be consistently propagated into the WUI domain without atmospheric feedback. The framework is demonstrated through two widely recognized WUI fire events: the 2025 Eaton Fire in the Los Angeles region and the 2017 Tubbs Fire in the Fountain Grove community. Model performance is evaluated using spatial agreement metrics between simulated and observed ignition and structure-loss patterns, alongside analyses of ignition mechanism attribution. Uncertainty in key model inputs including wind-gust variability, thermal radiation flux-time product thresholds, heat release rate parameters, and firebrand transport and spatial deposition parameters is addressed through systematic parameter exploration and scenario-based optimization, enabling uncertainty-aware and scalable WUI fire simulation. This inference-guided parameterization provides a data-informed mechanism for calibrating the numerical ignition model, improving predictive fidelity while preserving computational scalability, and thereby enhancing interpretability and predictive robustness under uncertain environmental forcing.

Keywords: Wildland urban interface, physics-informed wildfire modeling, ignition mechanisms, firebrands, thermal radiation, direct-flame contact, parametric uncertainty, population-based optimization

Speaker



Devasmit Dutta

UCLA

ID 883: Inverse method quantification and validation of the hysteretic, temperature-dependent thermal properties of spray-applied fire resistive material (SFRM) up to 1100 °C

5:20 PM – 5:40 PM

Author(s): Jumari Robinson, National Institute of Standards and Technology (NIST)

Spray-applied fire resistive material (SFRM) is the most common form of passive fire protection used in steel structures in the United States. The temperature-dependent thermal properties of SFRMs are seldom provided by manufacturers but typically required for accurate structural-fire simulations. There have thus been several academic studies focused on quantifying these properties, however the results of these studies often conflict with each other for similar materials. Previous work has shown that the wide range of SFRM thermal properties reported in the literature yield numerically-predicted steel temperatures that vary up to 800 °C, and most of these predicted temperatures do not align with the large-scale experimental observations of NIST and others. Due to equipment limitations, most previous studies do not produce measurements beyond 750 °C. None provide information regarding the hysteretic effects of the irreversible chemical changes caused by heating, such as loss of free and chemically bound moisture. This study thus adopts an inverse method approach, wherein kilogram-scale samples of SFRM are heated to a maximum of 1100 °C, and the temperature response of the cross-section is recorded directly by embedded thermocouples. Several different specimen sizes, heating rates, and heating-cooling cycles (for hysteresis) are employed, and the temperature response of the cross-section is used to algorithmically optimize the thermal properties of representative finite element models. The trained properties from the different experiments are then cross validated against each other. Final validation is performed using computational fluid dynamics and heat conduction models of three full-scale compartment fire tests previously performed at NIST.

Speaker



Jumari Robinson

Research Structural Engineer | National Institute of Standards and Technology (NIST)

ID 293: Quantifying residential ventilation ratios for wui fire risk

5:40 PM – 6:00 PM

Author(s): Serdar Selamet, Exponent; Gamze Dogan, Konya Technical University; Zafer Yilmaz, University of California Los Angeles; Liana Wang, Stanford University; Ertugrul Taciroglu, University of California Los Angeles

Post-ignition structure-to-structure fire spread in dense Wildland–Urban Interface (WUI) communities is strongly governed by ventilation-controlled burning and the resulting radiative heat flux emitted from building façades. However, most large-scale WUI risk assessments rely on simplified or assumed ventilation conditions, limiting the fidelity of enclosure fire modeling and inter-building exposure estimates. This study focuses on improving the estimation of wall-specific ventilation (opening) ratios for residential structures and integrating this information into a computational framework for a WUI structural vulnerability index that explicitly targets structure-to-structure separation distances and post-ignition radiative heat flux exposure emitted from structures. Street-level imagery from Google Street View and post-event drone imagery archived in the NHERI Data Depot are compiled for residential structures in fire-affected regions of Los Angeles. An image-based, text-prompt-guided object detection algorithm is developed to automatically detect exterior wall openings, including windows and doors, and to quantify their sizes, locations, and distributions along individual façades. These detected openings are used to compute façade-specific opening area ratios, which directly define compartment ventilation conditions governing ventilation-limited, post-flashover fire behavior. The extracted ventilation ratios are incorporated into enclosure fire models to improve estimation of façade-level heat release behavior and the resulting radiative heat flux directed toward neighboring buildings, replacing uniform or assumed opening conditions commonly used in cluster-scale analyses. The refined ventilation characterization is then used to enhance an existing building- and cluster-level vulnerability framework, discussed elsewhere, by more accurately resolving the coupling between façade exposure, separation distance, and radiative transfer. The proposed approach provides a scalable pathway for incorporating image-derived ventilation metrics into post-ignition fire spread assessment and supports more physically grounded identification of high-risk building configurations in WUI communities.

Speaker



Serdar Selamet

Managing Engineer Consultant | Exponent Inc.

MS 007: Advances in Computer Vision, Deep Learning, & Artificial Intelligence for Structural Monitoring, Inspections, and Digital Twins

4:00 PM – 6:00 PM | Location: HUMN 135

Chair(s): Vedhus Hoskere; Mohammad Jahanshahi; Jian Li; Wei Song

Moderators



Wei Song



Vedhus Hoskere

Assistant Professor | University of Houston

ID 917: Integrating Hierarchical Deep Learning and RAG-based LLM Agent for Rapid Post-earthquake Building Damage Assessments

4:00 PM – 4:20 PM

Author(s): CHENG-JU TSAI, National Taiwan Universities, Civil Engineering of Computer Aided Engineering; Rih-Teng Wu, National Taiwan Universities, Civil Engineering of Computer Aided Engineering

Regions vulnerable to earthquakes necessitate robust, scalable mechanisms for rapid post-earthquake structural assessment, particularly due to limited resources and the bottleneck of deploying licensed engineers to evaluate widespread residential damage immediately following seismic events. This study proposes an integrated, multi-modal artificial intelligence framework enabling non-experts/citizens to conduct preliminary rapid damage assessment via a web-based interface. Our proposed methodology begins with rapid damage assessment to identify visual failure patterns in critical structural components. The outcomes of visual analysis are then seamlessly combined with a Large Language Model (LLM) component to generate detailed damage reports, context-aware explanations, as well as recommendations for further assessments. This two-step process ensures that original damage detection results are converted into actionable intelligence for the user. In the first step, visual damage assessment module is developed using a rigorous dataset of over 1,000 images, collected from disaster relief organizations and open sources, featuring components such as —walls, columns, and beams —exhibiting cracks, spalling, and exposed rebar. These patterns were annotated by engineers and used to train hierarchical deep learning (DL) models, including YOLO for damage detection and localization, Vision Transformers (ViT) for damage pattern classification, along with U-Net variants for precise semantic segmentation. A rule-based inference algorithm synthesizes these outputs to provide repair cost estimates and categorize structural risk into three safety levels: immediate evacuation, requiring professional inspection, and no concerns. These safety levels are aligned with the National Center for Research on Earthquake Engineering (NCREE) guidelines. Results demonstrate that the proposed hierarchical DL modules , achieves 85% accuracy in damage severity classification, while segmentation models yield an F1 score of 81% and a mean Intersection over Union (mIoU) of 68.2%. In the second step, to address the gap between DL outputs and cognitive understanding, the proposed approach develops a domain-specific conversational agent built upon a Retrieval-Augmented Generation (RAG) architecture. By fine-tuning compact Large Language Models (LLMs) on a specialized corpus of structural and earthquake engineering literature, the LLM agent is fed with consolidated DL to produce context-aware, scientifically grounded interpretations to the public/non-expert user. This work ultimately presents a holistic, automated pipeline that enables citizens to perform rapid preliminary damage assessments, thereby relieving the burden of professional inspectors, leading to enhanced community resilience for post-earthquake decision making.

Speaker



Cheng-Ju Tsai

National Taiwan University

ID 945: CrackSegFlow: Controllable Flow Matching Synthesis for Generalizable Crack Segmentation with a 50K Image–Mask Benchmark

4:20 PM – 4:40 PM

Author(s): Babak Asadi, University of Illinois Urbana–Champaign; Peiyang Wu, University of Illinois Urbana–Champaign; Mani Golparvar-Fard, University of Illinois Urbana–Champaign; Ramez Hajj, University of Illinois Urbana–Champaign

Defect segmentation is central to computer vision-based inspection of infrastructure assets during both construction and operation, yet deployment remains limited by scarce pixel-level labels and domain shift across environments. We introduce CrackSegFlow, a controllable flow-matching synthesis framework that generates photorealistic crack images conditioned on binary masks while preserving strict mask–image alignment. The image generator couples topology-preserving mask injection with boundary-gated modulation to maintain thin-structure continuity and suppress texture-driven false positives. A second, class-conditional flow-matching model synthesizes crack masks with explicit control over crack coverage, enabling balanced, topology-diverse paired data without additional manual annotation. To further diversify illumination and surface artifacts, we inject synthesized crack masks into crack-free backgrounds, reducing false positives caused by shadows, joints, and pavement markings. Experiments on five benchmarks spanning four asphalt datasets and the crack class of a concrete-domain dataset show consistent gains under an established hybrid CNN–Transformer segmentation backbone with a fixed training protocol. Using real plus synthesized pairs, in-domain performance improves on average by 5.37 mIoU and 5.13 F1, and target-guided cross-domain synthesis yields average gains of 13.12 mIoU and 14.82 F1 using only limited target mask statistics. Compared with diffusion-based semantic synthesis, CrackSegFlow enables substantially faster deterministic sampling and improves fidelity and mask–image alignment for thin-structure crack geometry. Finally, we release CSF-50K, a public dataset of 50,000 paired crack images and pixel-accurate masks for large-scale benchmarking of generalizable crack segmentation.

Speaker



Babak Asadi

University of Illinois Urbana-Champaign

ID 976: An Uncertainty-Aware Computer Vision Approach to Quantifying Element-Level Conditions in Bridges

4:40 PM – 5:00 PM

Author(s): Parham Bakhtiari, Utah State University; Mohsen Zaker Esteghamati, Utah State University

The resilience of transportation networks against natural hazards relies heavily on the structural integrity of aging bridge inventories, which facilitate trade and access to essential services. However, conventional manual inspection to assess these assets is costly, time-consuming, and poses safety risks to inspectors. While automated inspection methods utilizing computer vision (CV) and unoccupied aerial vehicles (UAVs) have improved defect detection, they often lack the semantic context necessary to link damage to specific structural elements. This limitation prevents the translation of raw visual data into element-level damage assessments required for actionable maintenance planning aligned with standard engineering protocols.

To address this disconnection, this study presents a context-aware framework designed to convert raw inspection imagery into quantitative condition assessments. The proposed methodology employs a dual-model architecture utilizing Mask2Former with Swin Transformer backbones to perform two complementary tasks: (1) instance segmentation to delineate critical structural elements (e.g., gusset plates, piers) and (2) semantic segmentation to classify defects. A probabilistic late fusion approach subsequently integrates these outputs using set-theoretic operations to intersect element masks with defect class masks, thereby quantifying the extent to which each critical element is compromised.

The framework is evaluated across two distinct infrastructure domains. First, using the COCO-Bridge dataset for steel bridges, the model achieved a coefficient of determination (R^2) of 0.93 between predicted and ground truth corrosion ratios, generating outputs directly aligned with the American Association of State Highway and Transportation Officials (AASHTO) Manual for Bridge Element Inspection (MBEI). Second, in the context of post-earthquake assessment of reinforced concrete bridges using the IDEA and GYU-DET datasets, the framework identified element-wise defects such as spalling and reinforcement corrosion with F1-scores exceeding 75%. Significantly, the output of this framework is machine-readable and can be directly ingested into a digital twin or building information model to support long-term asset management.

To validate reliability for safety-critical decision-making, an uncertainty quantification module utilizing Monte Carlo Dropout was implemented. The analysis showed that geometric complexity in components such as gusset plates constitutes the primary source of variance in instance segmentation, whereas semantic ambiguity governs uncertainty in corrosion intensity classification. Despite these capabilities, the study acknowledges limitations regarding dataset diversity, as the model was trained on images from only a few distinct bridges. Furthermore, performance degraded in poor-lighting environments beneath bridge superstructures due to the interplay of shadow and light, and results were affected by annotation quality characterized by imprecise boundaries. Future work will address these gaps to further enhance the utility of automated systems in resilience-based engineering.

Speaker



Parham Bakhtiari

Ph.D. Student | Utah State University

ID 965: Efficient UAV Bridge Inspection by Integrating Risk-Informed Decision-Making, LLM-Powered Deterioration Modeling, and Occlusion-Aware Coverage Analysis

5:00 PM – 5:20 PM

Author(s): Delaram Hassanlou, University of Houston; Vedhus Hoskere, University of Houston

Bridges are critical national assets, yet they progressively deteriorate over time, making reliable inspections essential for safety and maintenance planning. Current mandated manual inspections remain costly, labor-intensive, hazardous, limited in coverage, and highly dependent on subjective judgment, motivating the need for scalable and objective inspection alternatives. Recent advances in sensing and robotics have accelerated the adoption of UAVs for bridge inspection by enabling rapid, repeatable, and multimodal data collection to support automated condition monitoring. Despite these advantages, standard UAV inspection missions are often slow and densely executed, generating large and frequently redundant datasets while still failing to ensure complete visibility due to occlusions, and collected imagery may remain insufficient for detecting critical defects such as cracks. Prior work has explored coverage path planning and flight-parameter tuning to improve mission efficiency, but most approaches remain primarily geometry-driven and rely on fixed sensing assumptions or predefined priorities, without explicitly addressing occlusion-aware visibility, resolution-constrained defect detectability, or bridge-specific condition-driven prioritization. To address these gaps, this paper proposes a condition-aware, risk-informed UAV inspection framework that jointly integrates inspection reliability, surface coverage, and flight efficiency into a unified decision-making process for flight planning and parameter selection. This study first proposes a pipeline for data-driven probabilistic crack deterioration modeling from historical inspection reports data through LLM-based damage extraction and alignment for dataset construction, providing data-driven estimates of defect evolution and current condition of the bridge. Next, a UAV-specific physics-informed probability-of-detection model is proposed which is calibrated using real data, that captures the distance-dependent reliability of detecting fine-scale defects such as cracks. These outputs are then integrated into a novel risk-of-inspection formulation that combines detection uncertainty with consequence and maps results to interpretable linguistic descriptors to support inspection prioritization. Key flight parameters, including standoff distance and gimbal angle are treated as explicit decision variables, where standoff distance governs image scale and detectability while gimbal angle improves visibility of non-planar components and mitigates occlusion in complex bridge components. To ensure that risk-satisfying configurations also provide adequate visibility, the framework evaluates candidate parameter combinations using synthetic camera poses and flight paths, and quantifies surface coverage through raycasting-based analysis that explicitly accounts for occlusion prior to deployment. By optimizing flight parameters under joint risk, time and coverage requirements, the proposed end-to-end framework enables UAV inspection configurations that are structurally meaningful, coverage-aware, and practically deployable for routine bridge inspections.

Speaker



Delaram Hassanlou

PhD Student | University of Houston

ID 1017: BridgeEQA: Virtual Embodied Agents for Real Bridge Inspections

5:20 PM – 5:40 PM

Author(s): Subin Varghese, University of Houston; Joshua Gao, University of Houston; Asad Rahman, University of Houston; Vedhus Hoskere, University of Houston

Deploying embodied agents that can answer questions about their surroundings in realistic real-world settings remains difficult, partly due to the scarcity of benchmarks that faithfully capture practical operating conditions. We propose infrastructure inspection as a compelling domain for open-vocabulary Embodied Question Answering (EQA): it naturally demands multi-scale reasoning, long-range spatial understanding, and complex semantic relationships, while offering unique evaluation advantages via standardized National Bridge Inventory (NBI) condition ratings (0-9), professional inspection reports, and egocentric imagery.

We introduce BridgeEQA, a benchmark of 2,200 open-vocabulary question-answer pairs (in the style of OpenEQA) grounded in professional inspection reports across 200 real-world bridge scenes with 47.93 images on average per scene. Questions require synthesizing visual evidence across multiple images and aligning responses with NBI condition ratings. We further propose a new EQA metric Image Citation Relevance to evaluate the ability of a model to cite relevant images.

Evaluations of state-of-the-art vision-language models reveal substantial performance gaps under episodic memory EQA settings. To address this, we propose Embodied Memory Visual Reasoning (EMVR), which formulates inspection as sequential navigation over an image-based scene graph: images are nodes, and an agent takes actions to traverse views, compare evidence, and reason within a Markov decision process. EMVR shows strong performance over the baselines.

Speaker



Vedhus Hoskere

Assistant Professor | University of Houston

ID 740: Crowdsourced mobile sensing-based bridge monitoring: Current progress and a roadmap for the future

5:40 PM – 6:00 PM

Author(s): Liam Cronin, Lehigh University; Debarshi Sen, Southern Illinois University Carbondale; Giulia Marasco, Florida International University; Iman Dabbaghchian, Lehigh University; Thomas Matarazzo, United States Military Academy; Shamim Pakzad, Lehigh University

Vibration-based bridge modal identification is a key component of transportation infrastructure monitoring but traditionally relies on fixed sensor arrays that are costly, labor-intensive, and difficult to scale. Recent advances in mobile sensing have demonstrated the potential of crowdsourced vibration data collected from smartphones carried by pedestrians and passengers as an alternative means of indirectly sensing bridge dynamics. While promising results have been reported in laboratory and field studies, widespread implementation requires a systematic understanding of vehicle–bridge interaction effects and the suitability of different mobile data sources for modal identification. This work is a review of existing methods and presents a roadmap for scalable bridge modal identification using dynamically diverse crowdsourced datastreams, including passenger cars, buses, bicycles, and scooters. By analyzing the influence of vehicle dynamics and data heterogeneity, this work highlights pathways for reliable modal extraction in urban environments. The findings support the feasibility of large-scale, cost-effective mobile sensing paradigms to enhance data-driven decision-making and resilience of transportation infrastructure.

Speaker



Giulia Marasco

Assistant Professor | Florida International University

MS 017: Learning-Based Structural Health Monitoring Under Limited Damage Data: Adaptation, Transfer, and Unsupervised Approaches

4:00 PM – 6:00 PM | Location: HUMN 125

Chair(s): Xiao Liang; Kareem Eltoumy; Jian Li

Moderators



Kareem Eltoumy

AI Researcher | Hedral Inc



Jian Li

Deane E. Ackers Professor | University of Kansas

ID 70: Domain-Adaptive Signal Segmentation for Vortex-Induced Vibration Detection Across Long-Span Bridges

4:00 PM – 4:20 PM

Author(s): Sunho Lee, University of Seoul; Sunjoong Kim, University of Seoul

Deep learning–based vortex-induced vibration (VIV) detection models for long-span bridges often exhibit a strong dependence on the training bridge, which leads to severe performance degradation when they are deployed on unseen bridges. As a result, bridge-specific data collection and repeated model retraining are required, making sustainable deployment in real-world structural health monitoring difficult. To address this issue, this study proposes an unsupervised domain adaptation (UDA) framework that uses unlabeled target-domain data to reduce structural domain discrepancies between different bridges. The framework is built on a Bi-LSTM–attention architecture that performs signal-level segmentation of bridge responses for pointwise VIV detection, while a maximum mean discrepancy (MMD)–based loss is employed to align feature distributions between the source and target domains and reduce cross-bridge domain shift. Specifically, domain adaptation is performed on normal vibration states shared across bridges, enabling the model to detect VIV in the target bridge as deviations from the aligned normal-state representation. To evaluate the proposed framework, we designed three experimental scenarios. In Case 1, the performance of a source-only baseline model is compared with that of the UDA model on a target bridge unseen during training, highlighting the effect of domain adaptation for cross-bridge transfer. In Case 2, the framework is trained using one source domain and multiple target domains to examine its generalization capability within the adapted domains across different bridge structures. In Case 3, the model trained in Case 2 is further evaluated on an unseen bridge to assess its out-of-domain generalization performance. The results demonstrate that the proposed UDA framework consistently outperforms the source-only baseline, enhancing cross-bridge generalization and improving VIV detection accuracy in both in-domain and out-of-domain scenarios.

Speaker



Sunho Lee

Mr. | University of Seoul

ID 226: Consistency-guided Model-contrastive Federated Learning for Scalable Road Damage Detection

4:20 PM – 4:40 PM

Author(s): Ziluo Xiong, Colorado State University; Gaofeng Jia, Colorado State University

Timely and accurate detection of road damage has been a critical task in structural health monitoring to initiate informed resource allocation and prevent delayed actions from causing more severe consequences and higher rehabilitation costs. Machine learning is increasingly adopted to automate road damage detection by using object detectors to analyze widely accessible street-level images/videos. However, most of these detectors are developed under a centralized learning paradigm, where data from diverse sources must be consolidated and processed at a single location, creating high costs for data transmission/storage and significant privacy concerns. To overcome these limitations, this study proposes a novel federated learning method, termed COMOON, that enables collaborative development of object detectors across different entities without data sharing. The core idea is to leverage collective knowledge to learn a generalized feature extractor that captures domain-invariant representations shared across entities and to utilize this extractor to tailor the detector for each entity. More specifically, a swapping-based knowledge distillation scheme is proposed to guide the global aggregation process toward cross-domain consistency in feature extraction. In parallel, a multi-scale model-contrastive learning strategy is developed to align local learning objectives with the aggregated knowledge, thereby regularizing optimization dynamics and facilitating convergence to a stable and well-generalized optimum. The resulting generalized feature extractor can help build well-performing local personalized models, as domain-invariant representations tend to encode more discriminative and robust features of road damage. Extensive experiments on the RDD2022 dataset, using four countries as independent data owners, reveal that COMOON consistently outperforms conventional federated learning methods, personalized variants, and even centralized learning in some cases. Grad-CAM visualizations and t-SNE analyses demonstrate that COMOON tends to concentrate on true damage regions in inference and produce feature spaces in which data from different domains are more mixed. Ablation studies further confirm the complementary roles of swapping-based knowledge distillation, multi-scale model-contrastive learning, and a random server rotation strategy. Finally, hyperparameter analyses provide practical guidance for balancing domain-invariance, personalization strength, and communication cost in future deployments. Beyond road damage detection, the proposed method offers a general approach for building collaborative yet locally adapted object detection models among heterogeneous stakeholders without data sharing, directly supporting scalable, privacy-preserving monitoring of critical infrastructures.

Speaker



Ziluo Xiong

Graduate Research Assistant | Colorado State University

ID 466: Complexity-Aware Curriculum Learning with Iterative Annotation and Refinement for Damage Segmentation

4:40 PM – 5:00 PM

Author(s): Vahidreza Gharehbaghi, University of Kansas; Jian Li, University of Kansas; Hang Zhao, University of Kansas; Rémy D. Lequesne, University of Kansas; Caroline Bennett, University of Kansas

Vision-based structural health monitoring (SHM) has become a practical, non-contact solution for damage assessment in large-scale civil infrastructure, enabling rapid and cost-effective inspection using cameras deployed on fixed platforms and unmanned aerial vehicles (UAVs). Despite the success of deep learning for automated damage detection and segmentation, its effectiveness is often limited by the scarcity of high-quality labeled data. Generating accurate annotations for heterogeneous damage types such as cracks and spalling is labor-intensive, time-consuming, and susceptible to inter-annotator variability, which can significantly hinder model generalization and reliability in real-world field conditions.

To address this challenge, this study proposes a data-efficient training framework that integrates complexity-aware curriculum learning, iterative pseudo-labeling, and automated annotation refinement. A hybrid sample-ranking module first estimates damage complexity in unlabeled images using complementary cues from classical image processing techniques such as texture and edge statistics, contrast, and morphological descriptors, together with a deep feature-based classifier. This ranking enables an easy-to-hard curriculum that stabilizes network training and improves robustness. In the proposed implementation, damage complexity is quantified by the proportion of crack pixels per image, and the dataset is divided into three difficulty levels. A YOLO-based segmentation model is then trained progressively from low- to high-complexity samples. The framework further incorporates an iterative pseudo-labeling strategy guided by active learning principles, in which a teacher model generates pseudo-labels for previously unlabeled data. To reduce error accumulation from imperfect pseudo-labels, we introduce a pipeline that leverages the Segment Anything Model (SAM) to obtain high-resolution damage masks, followed by morphology post-processing to correct boundary inaccuracies and suppress artifacts. The proposed approach is validated on a real-world concrete dam dataset containing cracks and spalling damage. Results demonstrate improved segmentation accuracy with reduced manual annotation effort, highlighting the framework's potential for scalable deployment of deep learning-based SHM under limited labeled-data budgets.

Speaker



Vahidreza Gharehbaghi

Graduate research assistant | University of Kansas

ID 690: Active Learning for Surrogate-Assisted Structural Model Updating in a Sensitivity Based Singular Value Decomposition Reduced Subspace

5:00 PM – 5:20 PM

Author(s): Tazwar Bakhtiyar Zahid, Texas A&M University; Xiao Liang, Texas A&M University

Building stiffness parameters may change over time due to environmental effects, material aging, or structural damage under earthquakes. Accurately tracking these changes is necessary for reliable structural assessment and performance prediction. Updating the parameters involve using limited and noisy field measurements combined with Finite Element Models (FEM). However, this conventional approach is computationally expensive, and the solution can often be ill-posed. Moreover, the multiple structural elements of a multi-story, multi-bay system introduce a new layer of complexity due to high-dimensional parameter spaces and severe identifiability issues.

To address these limitations, the study proposes a surrogate-assisted model updating framework with active learning and sensitivity-assisted dimensionality reduction to achieve efficient and stable estimation of spatially variable structural parameters. First, the Singular Value Decomposition (SVD) of the response sensitivity matrix is used to identify data-informed parameter directions, which yield a reduced parameter space suitable for updating. This enables the reduction of the high-dimensional parameter space to a lower-dimensional subspace that retains the directions most sensitive to available measurements.

Within the reduced subspace, a forward surrogate model is then trained to map the reduction in stiffness parameters to the modal response using FEM data. Initial training samples are generated through Latin Hypercube Sampling (LHS) to ensure adequate coverage of the reduced parameter domain. To further enhance the sampling, an active learning strategy has been employed, utilizing the Extended Expected Feasibility Function (XEFF) criteria to enrich the training set. This XEFF strategy adaptively enriches the training set by selecting new finite element evaluations that maximize the information gain across multiple modal response quantities.

Once the surrogate is trained, the model parameters are estimated by minimizing the objective function, which is defined by the residual between the surrogate model prediction and the field measurements, while accounting for measurement uncertainty. This methodology would ensure an efficient and stable update of spatially variable structural parameters while substantially reducing the number of FEM evaluations under limited data and computational budgets.

Speaker



Tazwar Bakhtiyar Zahid

Ph.D Student | Texas A&M University, College Station

ID 692: A Generative Model-Assisted FEMU Framework for Localized Structural Damage Identification

5:20 PM – 5:40 PM

Author(s): Ben Li, Texas A&M University; Xiao Liang, Texas A&M University

Structural Health Monitoring (SHM) is critical for ensuring the long-term safety and serviceability of civil infrastructure. Although deep learning has advanced vibration-based SHM, most approaches in structural damage identification tasks remain data-driven, and methods that incorporate physics still often assume a known baseline model—an assumption rarely satisfied in practice. When structural parameters are unknown, finite element model updating (FEMU) offers a physics-based way to calibrate a numerical model using measured responses by adjusting model parameters to match the observations, thereby enabling inverse estimation of structural properties for damage identification. However, most FEMU studies update material properties as global parameters shared by the entire structure. As a result, the updated model primarily reflects structure-level equivalent changes rather than spatially localized variations, which fundamentally limits damage localization.

In this study, we propose a generative model-assisted FEMU approach that integrates generative modeling with global optimization to improve localized damage identification and severity estimation. Instead of updating a single global parameter, material properties are represented as a spatially varying field. To address the resulting high-dimensional inverse problem, a Variational Autoencoder (VAE) is trained to learn a low-dimensional latent representation of material-parameter fields, enabling efficient generation of high-dimensional spatial fields via VAE decoding. The updating objective is formulated by matching measured and simulated acceleration time-history responses at sensor locations. Model updating is then performed in the latent space using Deep Networks for Global Optimization (DNGO), where a surrogate neural network guides the search by predicting the objective value and its uncertainty. Damage location and severity are then inferred by comparing the updated material-parameter field with a healthy baseline field.

The proposed approach is validated on a numerical case study of a nine-story reinforced concrete moment-resisting frame. Results show that the proposed approach captures localized stiffness-reduction patterns and achieves accurate damage localization and severity estimation under limited sensing, with manageable computational cost. This approach provides an effective pathway for incorporating parameter field identification into FEMU and supports practical vibration-based damage estimation in complex civil structures.

Speaker



Ben Li

PhD Student | Texas A&M University

ID 693: Structural Damage detection under Severe Data Scarcity via Instance Reweighting Approach

5:40 PM – 6:00 PM

Author(s): Yifeng Zhang, Texas A&M University; Xiao Liang, Texas A&M University

Data-driven structural damage detection methods have shown promising performance in controlled scenarios, yet their reliability in real-world structural health monitoring applications often depends on the availability of large training datasets. In practice, such data are rarely accessible. Only limited historical measurement data can typically be collected from in-service structures, while obtaining reliable damage labels requires expert inspection, field investigation, or maintenance records, all of which involve substantial effort and cost. As a result, there exists a fundamental mismatch between the data requirements of many learning-based methods and the data availability encountered in practical damage detection tasks. To address this challenge, this study investigates structural damage detection under a limited-data transfer learning setting, where both the available source data and the data from the target structure are severely constrained. Instead of assuming access to large unlabeled datasets for domain adaptation, the proposed approach explicitly exploits a small amount of labeled information from the target structure to guide the learning process. The approach is inspired by the TrAdaBoost framework and incorporates a sample reweighting mechanism during training. It allows the model to selectively reduce the influence of training samples that are less relevant to the target structure. In this way, limited target-domain supervision is used to mitigate negative transfer effects, even when the source dataset itself is small. The effectiveness of the proposed approach is examined through a comparison of three representative learning scenarios. These scenarios include: (i) a baseline method trained using only the limited labeled data available from the target structure, (ii) a conventional domain adaptation approach trained with fully labeled source data and unlabeled target data, and (iii) the proposed instance reweighting method trained with a small subset of labeled source data together with a small amount of labeled target data. This comparative design highlights the trade-off between data availability and learning effectiveness across different strategies. The results demonstrate that, despite operating under a significantly more constrained data availability, the proposed method can achieve performance comparable to conventional domain adaptation methods that rely on substantially higher data requirements. This highlights the proposed method as a practical approach to structural damage detection when data availability is highly constrained.

Speaker



Yifeng Zhang

PhD Student | Texas A&M University

MS 022: Integration of Physics-based Models with Data for Identification, Monitoring, Estimation, and Uncertainty Quantification

4:00 PM – 6:00 PM | Location: HUMN 1B50

Chair(s): Yang Wang; Hamed Ebrahimiyan; Babak Moaveni; Haeyoung Noh

Moderatorss



Yang Wang

Professor | Georgia Institute of Technology



Babak Moaveni

Professor | Tufts University

ID 634: Hierarchical Gaussian Process Modeling of Modal Quantities Residuals for Bayesian Updating of Structural Systems

4:00 PM – 4:20 PM

Author(s): Eleonora Maria Tronci, New York University; Mingming Song, Tongji University; Babak Moaveni, Tufts University

This study introduces an adaptive Hierarchical Bayesian Model Updating (HBMU) framework that incorporates Gaussian Process (GP) regression to model structured residuals in the modal predictions of structural systems. The approach employs an iterative training strategy: initiating from the maximum a posteriori (MAP) estimate of structural parameters, the framework constructs a dual-layer model comprising a physics-based forward simulator and a non-parametric GP surrogate. This surrogate captures the structure of prediction errors in modal parameters (frequencies and mode shapes) as a function of both parameters and contextual metadata. The GP training set is dynamically enriched; as the posterior distribution evolves during the updating loop, additional samples are targeted in regions of shifting probability mass, ensuring the surrogate accurately characterizes the residual surface where it matters most. Unlike traditional methods assuming independent, zero-mean Gaussian errors, this framework explicitly models systematic, condition-dependent discrepancies between model predictions and observed data. By learning these residual trends across varying operational conditions, such as test time and excitation intensity, the GP surrogate enhances uncertainty representation and improves generalization to unseen scenarios. The methodology is applied to experimental data from a two-story reinforced concrete frame with masonry infills, tested under varying excitation and damage scenarios. The resulting framework offers improved predictive accuracy and facilitates robust model validation, strengthening digital twin capabilities for real-time structural diagnostics.

Speaker



Eleonora Maria Tronci

Assistant Professor | New York University

ID 706: Physics-Guided Neural-Operator-Based Hybrid Digital Twins for Probabilistic Structural Damage Detection

4:20 PM – 4:40 PM

Author(s): Sikandar Ali Khokhar, Purdue University; Zixin Wang, University of Illinois at Urbana-Champaign; Mohammad Reza Jahanshahi, Purdue University

Structural health monitoring (SHM) through timely damage identification is essential for ensuring the safety, serviceability, and resilience of civil infrastructure. Data-driven anomaly-detection methods, such as autoencoders, have been widely used to learn healthy structural behavior from sensor measurements. However, purely data-driven approaches are sensitive to operational variability and often lack physical interpretability, limiting robustness for real-world deployment. This study presents a physics-guided, neural-operator-based structural digital twin for damage identification via anomaly detection. The proposed framework employs a Fourier Neural Operator (FNO) to learn mappings between continuous structural response fields in the spectral domain. By operating in Fourier space, the FNO efficiently captures long-range spatial and temporal dependencies and enables high-dimensional operator learning independent of discretization. In this work, the FNO learns the mapping between finite-element (FEM) response fields and measured structural responses. Using paired datasets collected exclusively in the healthy state, the FNO is trained to take FEM-predicted responses as input and predict the corresponding measured responses. Together, the FEM and the trained FNO form a physics-guided digital twin that represents the expected healthy behavior of the structure. During monitoring, damage is identified through anomaly detection on the prediction error between digital-twin predictions and sensor measurements. Since the FEM and learned FNO encode only the healthy FEM-to-structure mapping, damage-induced changes in stiffness, connectivity, or damping manifest as increased prediction error, providing a physically interpretable damage indicator. To enhance robustness, information is fused across multiple sensors and excitation locations using three fusion scopes: sensor-level fusion (SF), hierarchical sensor-to-excitation fusion (SF→EF), and joint sensor-and-excitation fusion (SF&EF). In addition to threshold-based voting, a Bayesian probabilistic fusion scheme is employed, where each sensor contributes a damage likelihood derived from its prediction error, and multi-sensor evidence is aggregated into a global damage probability. The framework is validated on both the ASCE benchmark structure and a geodesic dome under impact-based excitations. Results demonstrate the effectiveness of physics-guided neural-operator-based digital twins for reliable and interpretable structural damage detection.

Speaker



Zixin Wang

Dr. | University of Illinois Urbana-Champaign

ID 717: Model-Assisted Force Identification in Truss Bridges Using Deep Learning

4:40 PM – 5:00 PM

Author(s): Hyunjoong Kim, Liberty University; Sebastian Aviles, Liberty University

This study presents a numerical-model-assisted force identification framework. This framework uses numerical simulations to inject physical information into a data-driven learning process. Rather than relying solely on data, simplified or detailed numerical models are employed to guide the learning of deep neural networks, enabling improved force identification under limited data availability. To demonstrate the approach, numerical models with varying levels of fidelity are considered for two-dimensional and three-dimensional truss bridge simulations.

Speaker



Sebastian Aviles

Research Assistant Student | Liberty University

ID 839: Multiphysics Modeling and Model Updating of a Jacket-Supported Offshore Wind Turbine Using Measured Vibration and SCADA Data

5:00 PM – 5:20 PM

Author(s): Nasim Partovi-Mehr, Tufts University; Rad Haghi, Tufts University; Babak Moaveni, Tufts University; Eric Hines, Tufts University

Multiphysics models are often utilized for structural design, condition assessment, and response prediction of a system, such as the support structure of offshore wind turbines. Although multiphysics models are considered to be of high fidelity, discrepancies are often observed between the model predictions and actual data measurements from the real structure. The model updating process reduces the model parameter uncertainty by minimizing the differences between the model and the measured data through an optimization procedure. In this paper, such a procedure is applied to an instrumented GE Haliade 6-MW jacket-supported offshore wind turbine by updating the tower and substructure modulus of Elasticity (E) to minimize differences between modal parameters identified from one month of measurements and those obtained from the OpenSees model or predicted from surrogate models. Surrogate models, including a neural network and a polynomial regression fit, are used to replace the OpenFAST simulations. The results indicate that the fully coupled OpenFAST model provides a more physically consistent representation in the medium power range (0.5–4.5 MW) by reducing variability in the updated E, whereas the OpenSees model is more suitable for low and high categories, where pitch control and reduced aerodynamic loading limit the influence of aero-hydro-servo-elastic effects.

Speaker



Babak Moaveni

Professor | Tufts University

ID 854: A Proposition on the Solvability of Dynamic Model Updating Problems

5:20 PM – 5:40 PM

Author(s): Harry Ashimatey, Georgia Institute of Technology; Dahye Han, Georgia Institute of Technology; Santanu Dey, Georgia Institute of Technology; Yang Wang, Georgia Institute of Technology

Structural model updating aims to calibrate model parameters such that the predicted structural properties closely match those obtained from field measurements. Many existing studies rely on in-situ dynamic measurements from an as-built structure, from which natural frequencies and mode shapes are identified. Model updating is typically formulated as an optimization problem that minimizes discrepancies between simulated modal properties and those extracted from measurements.

A fundamental question concerns the amount of modal information required to uniquely identify an optimal set of structural parameters, i.e., the conditions under which the model updating problem is solvable. This study proposes a criterion addressing the solvability of dynamic model updating and examines its validity through carefully designed numerical examples. In addition, the study highlights the inherent non-convexity of the model updating optimization problem and illustrates its implications.

Speaker



Yang Wang

Professor | Georgia Institute of Technology

ID 972: Quantifying Long-Term Sensor Aging in a Field-Deployed Accelerometer Network

5:40 PM – 6:00 PM

Author(s): Manuel Salmeron, Purdue University; Shirley Dyke, Purdue University; Monica Kohler, California Institute of Technology

In structural health monitoring and seismology, it is commonly assumed that sensor measurement accuracy remains unchanged over time. However, field-deployed sensor networks are exposed to environmental conditions (e.g., temperature and humidity fluctuations) that may change sensor noise characteristics and sensitivity in the long-term. Beyond routine filtering and detrending, such long-term sensor aging is seldom quantified and is rarely accounted for in data post-processing and interpretation. This study leverages long-term noise-metric histories from a large MEMS accelerometer network deployed in California to calibrate and validate a stochastic physics-based model for sensor aging under realistic environmental exposure. We use a statistical approach to obtain sensor-specific aging signatures. Then, we calibrate the parameters of well-established physics-based degradation laws to match the observed noise-metric histories. The proposed model can be used to develop more durable and reliable sensor designs and to optimize maintenance and replacement decisions across sensor networks.

Speaker



Manuel Salmeron

Ph.D. Candidate | Purdue University

Ms 026: Modeling of Materials with Interfaces and Scales Using Physics-Based and Machine-Learning Methods

4:00 PM – 6:00 PM | Location: HUMN 150

Chair(s): Xiang Zhang; Pinlei Chen; Kamalendu Ghosh; Balavignesh Vemparala Narayana Murthy; Ravindra Duddu; Soheil Soghrati; Reza Abedi

Moderatorss



Balavignesh Vemparala

Dr. | Synopsys, Inc.



Ravindra Duddu

Associate Professor | Vanderbilt University

ID 789: Numerical Methods with Computational Intelligence for Materials Processing and Layered Additive Manufacturing

4:00 PM – 4:20 PM

Author(s): Arif Masud, University of Illinois Urbana-Champaign; Ignasius Wijaya, University of Illinois Urbana-Champaign

Coupled thermo-chemo-mechanical phenomena appear in many problems in advanced materials processing and additive manufacturing. This talk presents a computational framework for process modeling of materials wherein material properties evolve as a function of time together with the evolution of the geometric shape of the structure that is being printed in a layer-wise fashion. The class of Variational Multiscale Discontinuous Galerkin (VMDG) methods is discussed, and its unique features for problems with dominant interfacial physics and embedded constraints is discussed. In VMDG, a multiscale decomposition of the unknown fields into coarse- and fine-scales leads to a hierarchical system that describes physics at the global and the local levels, respectively. The fine-scale equations facilitate various modelling options that can be exploited to model finer features in the evolving physics of material evolution, in addition to addressing numerical issues of stability of such systems. This hierarchical structure with the local modeling feature leads to "residual-based self-monitoring of the modeled physics", thereby yielding a novel material modeling framework with embedded computational intelligence. The method is extended for Immersed 3D Printing wherein boundaries of the structure traverse through the fixed computational grids as the process of layering of the material evolves, facilitating tremendous flexibility in 3DP of complex geometric shapes. Several test cases are presented that highlight the significance of enhanced stability and higher spatial accuracy of the method for process modeling of advanced materials in additive manufacturing.

Speaker



Arif M

Professor of Engineering | University of Illinois

ID 790: Elastomers filled with liquid inclusions: Theory, numerical implementation, and results

4:20 PM – 4:40 PM

Author(s): Kamalendu Ghosh, Micron Technology

In this talk, the homogenization problem of an elastomer filled with liquid inclusions subjected to finite quasistatic deformations will be presented.

I will begin the talk by revisiting the relevant ingredients of kinematics, balance laws, and constitutive behavior with the goal of generalizing these discussions to account for interfacial forces. In doing so, I will emphasize the key role that residual stresses in the bulk play on the response of the material. Using these ingredients, I will then formulate the homogenization problem for the basic non-dissipative case when (i) the elastomer is a hyperelastic solid, (ii) the liquid inclusions are hyperelastic fluid, (iii) the interfaces feature their own hyperelastic behavior (which includes surface tension as a special case), and (iv) the inclusions are initially spherical.

I will then conclude the discussion by presenting results for incompressible Neo-Hookean elastomers embedded with a monodisperse distribution of incompressible liquid inclusions. The elastomer-liquid inclusion interfaces would feature a constant surface tension. While I will present computational results for finite deformations and finite volume fractions of inclusions, I will also present several insightful analytical results in the limits of small deformations and (i) dilute volume fractions, and (ii) at percolation

Speaker



Kamalendu Ghosh

Sr. R&D Engineer | Micron Technology

ID 849: Variational multiscale enrichment method for dynamic response of hyperelastic composites at finite deformation

4:40 PM – 5:00 PM

Author(s): Abhishek Arora, Vanderbilt University; Gloria Odenyo, Vanderbilt University; Caglar Oskay, Vanderbilt University

We present a new multiscale framework to model the dynamic response of heterogeneous hyperelastic materials undergoing large deformations. The ultimate objective of this work is to enable efficient simulation of dynamic impact response structures made of architected materials. The proposed framework is based on the variational multiscale enrichment (VME) method. The primary principle is the additive split of the displacement, velocity and acceleration fields through direct sum decomposition of the corresponding Sobolev spaces, which results in a system of multiscale governing equations derived in the variational form. This approach enables the simulation of wave propagation under scale-inseparable conditions, including short-wavelength regimes, while accounting for the effects of material and geometric nonlinearities on wave dispersion. The multiscale governing equations consist of coupled variational coarse- and fine-scale problems, where the micro-inertial effects are naturally incorporated. An operator-split procedure is used to iteratively integrate the semi-discrete equations for the coarse and fine scales until convergence is achieved. The coarse-scale problem is chosen to be integrated explicitly, while the fine-scale problem is integrated either explicitly or implicitly, using dissipative or non-dissipative time integration schemes. Numerical examples demonstrate that dissipative integration schemes outperform non-dissipative ones, such as the explicit central difference method, by avoiding spurious oscillations in certain cases. The multiscale approach is also employed to study the effects of material and geometric nonlinearities, as well as elastic stiffness contrast in heterogeneous microstructures, on wave dispersion and attenuation. The results obtained from the multiscale approach show close agreement with direct numerical simulations, validating its accuracy. This method provides a foundational framework for developing reduced-order multiscale models for dynamical response in architected materials, where the fine-scale problem can be replaced with a data-driven surrogate model, enabling more efficient simulations.

Speaker



Caglar Oskay

Professor | Vanderbilt University

ID 885: ϕ -DeepONet: A Discontinuity-Capturing Neural Operator

5:00 PM – 5:20 PM

Author(s): Sumanta Roy, Johns Hopkins University; Stephen T Castonguay, Lawrence Livermore National Laboratory; Pratanu Roy, Lawrence Livermore National Laboratory; Michael D. Shields, Johns Hopkins University

Interface problems are pervasive in science and engineering, arising in applications such as composite heat conduction, porous media flow, and biological transport, where heterogeneous subdomains interact through discontinuous coefficients and interface jump conditions. Accurate resolution of these discontinuities is essential, as interface errors often dominate the global solution. Classical mesh-based methods can achieve high accuracy but face significant challenges for complex or irregular interface geometries due to mesh generation and refinement costs. Recent advances in physics-informed machine learning offer mesh-free alternatives; however, most existing approaches for interface problems rely on physics-informed neural networks (PINNs) and require retraining when problem parameters change, limiting their use in parametric settings.

In this work, we introduce ϕ -DeepONet, a novel neural operator framework for learning solution operators of elliptic interface problems with discontinuous coefficients. Unlike existing domain-decomposition-based operator learning methods, whose complexity increases rapidly with the number of interfaces, the proposed approach embeds discontinuities directly into the operator architecture through a learned latent representation. Discontinuous input functions are handled using multiple branch networks, while interface information is encoded via a one-hot representation of subdomains and projected into a low-dimensional latent space. This latent variable augments the output function space and is incorporated into a modified trunk network, enabling the operator to represent discontinuous solution manifolds without explicit domain decomposition or mesh dependence.

The proposed ϕ -DeepONet framework is fully mesh-free, scalable to problems with multiple interfaces, and capable of generalizing across parametric variations without retraining. Numerical experiments on elliptic interface problems demonstrate that the method accurately captures solution discontinuities and interface behavior while maintaining computational efficiency. These results highlight the potential of ϕ -DeepONet as a robust and scalable operator-learning paradigm for a broad class of interface problems in scientific computing.

Speaker



Sumanta Roy

Graduate Student | Johns Hopkins University

ID 926: Elasto-Plastic Material Response with Neural Operators

5:20 PM – 5:40 PM

Author(s): Meer Mehran Rashid, Johns Hopkins University; Lori Graham-Brady, Johns Hopkins University

Accelerating the discovery and deployment of next generation materials demands methods that can rapidly navigate vast design landscapes while capturing nonlinear, path dependent behavior. Traditional physics based solvers provide this fidelity but at prohibitive computational cost, especially when iterating over microstructural designs, loading scenarios, and discretizations. We present a data driven framework that leverages neural operators and a multi resolution U Net to serve as a fast, reliable surrogate for finite element analysis (FEA), predicting stress trajectories for nonlinear materials in an autoregressive fashion. The core idea is to learn the evolution operator directly: given a short window of recent strain–stress history, the model forecasts multiple future FEM steps, thereby mimicking time marching. A Fourier Neural Operator branch captures long range, nonlocal interactions via global spectral kernels, providing stable forecasts across varying load magnitudes, while a U Net encoder–decoder resolves fine scale gradients and stress concentrations through multiscale feature fusion. The integrated design couples global operator learning with high frequency reconstruction, yielding accurate representation of localization, hysteresis, and sharp fronts with low computational overhead. We validate the framework on elastoplastic materials subjected to nonlinear pulse loading, demonstrating accurate intermediate stress predictions and close agreement with FEM trajectories across time and space. By coupling operator learning with multiscale spatial representations, this autoregressive pipeline offers a practical substitute for step wise nonlinear FEA, enabling rapid exploration of material behavior and accelerating data driven materials design.

Speaker



Meer Mehran Rashid

Graduate Student | Johns Hopkins University

ID 1019: Interface-Aware PINN Frameworks for Mechanical Response of Composite Materials: Comparative Analysis

5:40 PM – 6:00 PM

Author(s): Ali Hodaiei, University of Colorado, Boulder; Maryam Shakiba, University of Colorado, Boulder

This study investigates three Physics-informed neural networks (PINN) frameworks to assess their accuracy in predicting mechanical response of composite materials with strong material discontinuity. PINN frameworks provide a mesh-free computational method for solving solid mechanics problems; however, their practical application is often limited by severe ill-conditioning arising from the error amplification through first- and higher-order derivatives in the governing equations. These challenges are especially noticeable in heterogeneous materials with sharp material discontinuities, where localized prediction errors can lead to unstable training and poor convergence. To address these limitations, several PINN frameworks are developed in literature.

Accordingly, this study first evaluates the accuracy of mechanical response predictions in composite materials with strong material contrast using three different PINN frameworks: (i) PINN_A, a displacement only force-balance PINN in which two surrogate deep neural networks (DNNs) predict the displacement components as the sole primary outputs, with strain and stress fields obtained indirectly by automatic differentiation and enforced through force balance equations and boundary condition constraints; (ii) PINN_B, a multi-field force-balance PINN employing eight surrogate DNNs to independently predict displacement, strain, and stress components as direct outputs, while enforcing force balance, kinematic, constitutive, and boundary condition constraints within the loss function; and (iii) PINN_C, a multi-field PINN with the same direct outputs and governing constraints as PINN_B, augmented by an additional energy-based loss term derived from the principle of minimum potential energy to further stabilize training and improve convergence.

To improve training stability, independent DNNs are trained within each material subdomain corresponding to distinct constituent phases, while material interfaces are explicitly enforced as boundary conditions to ensure kinematic and traction continuity across phase boundaries. In addition, several training strategies, including hybrid optimization, distinct learning rates, and adaptive loss weighting, are employed to improve convergence behavior and reduce imbalance among loss residuals during training. The proposed frameworks are evaluated on benchmark fiber–matrix composite elasticity problems, using Abaqus finite element solutions as the reference baseline for comparison.

Furthermore, this study examines material interfaces beyond the perfectly bonded assumption by incorporating a cohesive zone formulation at the fiber–matrix interface, embedded into the PINN framework through interface traction–separation constraints. The interface is modeled as a cohesive layer with distinct stiffness values in the normal and shear directions. Damage initiation is governed by a maximum nominal stress criterion, whereby damage occurs when either the normal or shear traction reaches the corresponding interfacial strength, enabling the formulation to capture interface behavior up to the damage initiation.

This study highlights differences in stability and accuracy across PINN frameworks and shows that cohesive interface modeling enables PINNs to capture interfacial damage initiation. The results provide useful guidance for PINN applications in solid mechanics and improve predictive performance for composite materials through the explored frameworks and training methods.

Speaker



Ali Hodaiei
CUBoulder

MS 024: Experimental Mechanics in the Age of Big Data: Design, Sensing, and Integration

4:00 PM – 6:00 PM | Location: HUMN 1B90

Chair(s): Yiwen Dong; Kostas Kalfas; Mehrdad Aghagholizadeh

Moderatorss



Mehrdad Aghagholizadeh
Assistant Professor | Loyola Marymount University



Kostas Kalfas
Assistant Professor | Texas State University

ID 348: LLM-Assisted Pseudo-Experiment Generation for Physics-Based Synthesis of Structural Response Data

4:00 PM – 4:20 PM

Author(s): Ziluo Yao, University of Illinois Urbana-Champaign; Jinsi Guo, University of Illinois Urbana-Champaign; Billie F. Spencer Jr., University of Illinois Urbana-Champaign; Yiwen Dong, University of Illinois Urbana-Champaign

Experimental data are essential to structural response analysis for structural health monitoring and human–structure interaction, yet real-world experiments are often costly, sparse, and difficult to scale. Although physics-based simulations provide an attractive alternative, synthetic data often deviate from experimental reality due to simplified modeling assumptions, the formulation of which typically requires substantial domain expertise. Large language models (LLMs) can systematically structure experimental descriptions into consistent modeling considerations, leveraging patterns learned from pre-training on technical text and providing an interpretable approach to address this challenge. To close the gap between real-world experiments and physics-based simulations, this study introduces an LLM-assisted data synthesis framework that leverages LLMs to automate the experience-driven design of modeling methods and parameters to systematically configure physics-based simulations. Specifically, LLMs extract experimental design knowledge from experimental descriptions and further generalize it into new modeling configurations (e.g., varied loading conditions) for physics-based simulations, enabling the generation of realistic and physically consistent structural responses. The framework is validated by generating structural response data for a full-scale pedestrian bridge and comparing the synthetic data with field-collected data under varying pedestrian-induced excitations. Results show that the generated responses exhibit physical characteristics consistent with field-collected data, including natural frequencies, peak acceleration amplitudes, and power spectral density (PSD) features. For different loading conditions (e.g., pedestrian walking vs. jumping), these same physical characteristics vary in accordance with expected physical trends, demonstrating the framework's capability to generalize new structural configurations beyond those observed in the real-world experiments. Overall, the proposed framework enables the generation of structural response data that are difficult or impractical to obtain from real-world experiments, supporting systematic investigation of structural responses under configurable, reproducible simulation conditions.

Speaker



Ziluo Yao

Mr. | University of Illinois Urbana-Champaign

ID 390: Full field Dynamic Deformation of Passive Adaptive Marine Current Turbine Blades using Digital Image Correlation

4:20 PM – 4:40 PM

Author(s): Trevor Zalud, University of Washington; Katherine Van Ness, University of Washington; Richard Wiebe, University of Washington; Owen Williams, University of Washington

Marine current turbines offer an alternative renewable energy source, but they are subject to fluctuating loads that limit the fatigue life of the blades, rotor, and support structure. Active pitch control is a strategy for reducing loads and mitigating blade failure, however the added complexity introduces further failure mechanisms into the system. Passive load shedding is instead achieved in this study with Carbon Fiber Reinforced Polymer (CFRP) composites. Lab-scale blades are manufactured with a unidirectional CFRP spar with plies oriented 5° or 10° from the pitching axis. This creates a coupling between the streamwise bending of the blade and the pitching moment. The blade profile twists to decrease angle of attack under increasing flow conditions, thereby shedding load. Tests in both uniform and nonuniform flows were conducted, with an active grid being used to produce replicable shear flows and turbulence.

The turbine used is 45 cm in diameter, with two six-axis force/torque sensors, one on the rotor hub and the other at the root of one blade. This allows both blade-level and rotor-level loads to be measured. Flow characteristics were calculated from acoustic Doppler velocimeter measurements taken upstream of the turbine. Two methods of measuring deformation were used. First, a high-speed camera was positioned underneath the flume, focused on the rotor plane, to measure deformation at the blade tip. Second, Stereo Digital Image Correlation (DIC) was performed to extract full field deformation of the upstream/pressure surface of the blade during turbine operation. Two cameras were used for DIC, with one mounted on either side of the flume test section. A Hall effect sensor was used to trigger multiple images at various phase angles while the turbine swept through a range of tip-speed ratios (i.e., the ratio of the blade tip's tangential speed to that of the freestream flow), from 2 to 8.

We examined, from these results, the intra-cycle variation of blade deformations and loading. Streamwise bending and twist were compared at multiple radial positions along the blade for both uniform and nonuniform flows. The deformation at the tip in uniform flow was compared between the two methods, DIC and image processing of the in-plane footage. For each given tip-speed-ratio, streamwise deflection agreed within a 10% margin; the same comparison for twist angles yielded a maximum difference of 0.5° . For each set of deformations, corresponding blade and rotor operating loads are analyzed to assess the performance and effectiveness of the passive adaptive blades in mitigating intracycle load fluctuations compared to rigid aluminum blades. Results provide insight into the viability of passive pitch control in field-deployed marine current turbines.

Speaker



Trevor (Trev) Zalud

PhD Student | University of Washington

ID 653: Humidity and temperature effects in sand dampers

4:40 PM – 5:00 PM

Author(s): Kostas Kalfas, Texas State University; Liang Cao, University of Mississippi; Usama El Shamy, Southern Methodist University; James Ricles, Lehigh University; Nicos Makris, Southern Methodist University

There have been several recent studies which discuss the behavior of different response-modification devices when located in harsh environments; such as the bridge rubber bearings in cold weather, or the effects of infiltrated water and ice on friction pendulum bearings, or even the behavior of the newly developed shape memory alloy-based friction damper considering the temperature effects. To that end, this presentation will present an effort to develop a sustainable response-modification device which will not suffer from the challenge of viscous heating and the failure of its end seals. The relatively newly established pressurized sand damper is tested in extreme environmental conditions. The material that is enclosed in the damper housing and surrounds the moving piston is pressurized sand which is believed to be unaffected by either low or high temperatures, or even by the presence of water when it is subjected to shear loads. To that end, the proposed pressurized sand is tested under extremely high temperatures up to 60 °C to simulate some of the hottest temperatures ever recorded, such as the 1931 Tunisia, Africa 55°C, the 2017 Iran, Asia 54°C, the 2021 Italy, Europe 49°C, or the 1913 Death Valley, California 56.7°C; as well as to extremely low temperatures as low as 6°C to simulate as closely as possible extremely cold temperatures. This experimental campaign is conducted at the NHERI Lehigh Experimental Facility at ATLSS Engineering Research Center, at Lehigh University, where two customized double-ended pressurized sand dampers are subjected to cyclic sinusoidal input motions under different temperatures. Also, one pressurized sand damper that is built in the SMU Machine Shop is subjected to cyclic sinusoidal input motions with wet sand of different percentages of water content; an experimental campaign that is conducted in the SMU Structures Laboratory.

Speaker



Kostas Kalfas

Assistant Professor | Texas State University

ID 679: Field measurements of passive adaptive blades for a marine current turbine using fiber optic strain sensing

5:00 PM – 5:20 PM

Author(s): Katherine Van Ness, University of Washington Applied Physics Laboratory; Justin Burnett, University of Washington Applied Physics Laboratory; Benjamin Cunningham, University of Washington Applied Physics Laboratory; Jesse Doshier, University of Washington Applied Physics Laboratory; Tracy Tran, University of Washington Applied Physics Laboratory; Harlin Wood, University of Washington Applied Physics Laboratory; Christopher Bassett, University of Washington Applied Physics Laboratory

Blade failure remains the most common failure mode for tidal turbine deployments. Improved load prediction and load mitigation strategies are critical to prevent these failures. Passive adaptive turbine blades for marine current turbines offer a promising solution by deforming in response to flow conditions to shed excess loads. This research advances passive adaptive blade technology through field measurements of blade deflection and twist using distributed fiber optic sensors. This capability is valuable for interpreting turbine performance under realistic operating conditions, informing composite blade design and material selection, and validating complex bend-twist coupled blade models. Field measurements are particularly important for bridging the gap between lab- and field-scale performance of composite rotors, where fabrication constraints often limit adherence to theoretical scaling laws.

A 1-meter diameter turbine with bend-twist coupled carbon fiber blades was tested in Lake Washington, Seattle. The turbine was lowered below the bow of a research vessel which was driven at controlled speeds to simulate tidal currents. Testing covered inflow speeds of 1.0-1.4 m/s and rotation rates of 40-265 rpm. The turbine was instrumented with force/torque sensors on the hub and one blade, while a compact fiber optic interrogator housed within the rotating hub monitored 40 Fiber Bragg Grating (FBG) strain sensors distributed along both the pressure and suction surface of one blade. A data-driven calibration model relating strain measurements to blade deformation was developed using Sparse Identification of Nonlinear Dynamics (SINDy), trained on 190 laboratory load cases and validated with 60 additional load cases.

Field measurements successfully captured blade deformation over a range of operating conditions. At 1.0 m/s and 1.4 m/s, peak twist angles reached 2.0° and 4.5°, respectively, while tip deflections reached 10 mm and 16 mm (2.4-3.8% of blade length). These deformation magnitudes produced significant passive load shedding (i.e., up to 18% reduction in thrust compared to nonadaptive blades) without reducing mechanical power output. Higher inflow speeds of 1.5-1.7 m/s at low rotation rates were also tested, though combined high rotation rates and high inflow speeds exceeded sensor measurement range, which could be managed in future testing by reducing the number of FBGs per fiber. This work demonstrates the viability of fiber optic sensing for real-time blade strain and deformation monitoring in open-water deployments, supporting future applications in structural health monitoring, model validation, and continued development of passive adaptive blade technology for improved turbine reliability and costs.

Speaker



Katherine Van Ness

Dr. | University of Washington Applied Physics Laboratory

ID 188: Hybrid Experimental-Computational Framework for Modeling Deployable Ground Anchors

5:20 PM – 5:40 PM

Author(s): Khuzaima Hummad, University of Illinois Urbana-Champaign; Ann C. Sychterz, University of Illinois Urbana-Champaign

Deployable ground anchors employ compliant attachments to increase load capacity through geometric transformation during installation, offering a material-efficient alternative to conventional deep foundations. Reducing material usage in underground anchoring systems lowers transportation demands, installation energy, and associated fuel consumption, supporting more sustainable geotechnical infrastructure. However, modeling deployable underground structures during installation is challenging due to large rotations, evolving contact conditions, and soil disturbance. Existing approaches treat soil as a boundary condition or simplified stiffness, limiting their ability to capture load transfer in systems undergoing significant geometric change.

This study presents a hybrid experimental–computational framework that treats soil as an active structural member within a Dynamic Relaxation (DR) formulation. DR is an incremental-iterative method of static analysis that can accommodate geometric nonlinearities, making it well suited for systems that undergo large deformations. Small-scale experiments in uniform silica sand use ink-tracking to visualize shear plane development during deployment of compliant anchor attachments. Measurements of disturbed soil extent, deployment kinematics, and applied torque quantify the effective soil volume engaged and enable stiffness calibration.

The experimental data informs a DR-based form-finding model using an equivalent bar-and-hinge representation. Soil resistance is modeled as a structural member whose length and cross-sectional area are derived from observed shear plane geometry and disturbed volume, while stiffness is calibrated from measured deployment forces. This preserves mechanics consistency while avoiding expensive continuum modeling.

The framework predicts deployment forces within 25% of experimental measurements on average. A key finding is that soil resistance mobilizes approximately twice the geometric contact area due to stress redistribution and shear band formation beyond the direct contact zone. Comparative analyses show predicted forces depend strongly on how soil stiffness is defined, emphasizing the need for experimental calibration. Internal force distributions in structural members show similar agreement with measurements under quasi-static deployment in homogeneous sand.

This methodology provides a scalable approach for modeling deployable underground systems by incorporating soil as a mechanical member informed by experimental observations. The framework establishes foundations for future studies on connection design, cyclic loading, and long-term anchor performance, advancing experimental analysis by demonstrating how image-based measurements directly inform mechanics-based soil-structure models.

Speaker



Khuzaima Hummad

Research assistant | University Of Illinois Urbana Champaign

ID 648: Hypernetwork-Based Structural Response Estimation Across Variable Structural Configurations

5:40 PM – 6:00 PM

Author(s): Haifeng Wang, Washington State University

Efficient and accurate estimation of structural response under dynamic loading remains a central challenge in engineering mechanics, particularly when structural properties, geometry, and loading conditions vary across a population of systems. High-fidelity numerical simulations provide reliable solutions but become computationally prohibitive for large-scale parametric studies, real-time assessment, or regional-scale analyses. While data-driven surrogate models have shown promise for accelerating response estimation, most existing neural-network-based approaches are trained for a single structure and require retraining when applied to new configurations.

This work presents a hypernetwork-based framework for structural response estimation that enables a single learned model to adapt to multiple structures without retraining. In the proposed approach, a hypernetwork generates the parameters of a response-estimation neural network conditioned on a set of structural descriptors, such as geometric, dynamic, and material properties. By explicitly learning the mapping between structural features and network parameters, the method captures how response operators vary across the structural parameter space, allowing rapid deployment to previously unseen configurations.

The framework is evaluated through nonlinear dynamic response estimation problems representative of structural mechanics applications. Training data are generated using high-fidelity numerical simulations, while the trained hypernetwork is tested on structures not included in the training set. Results demonstrate that the proposed approach achieves high accuracy in time-domain response prediction while maintaining strong generalization across structural variability. Compared with conventional fixed-parameter neural networks, the hypernetwork formulation significantly improves adaptability and eliminates the need for structure-specific retraining.

To further enhance data efficiency and robustness, a knowledge-enhanced learning strategy is incorporated by embedding governing physical relationships into the training objective. This hybrid formulation reduces training data requirements and improves generalization under limited or noisy data conditions. Computational studies show that the proposed surrogate achieves substantial speedups relative to full-order simulations, enabling efficient response estimation for large ensembles of structures.

The proposed hypernetwork-based approach offers a scalable and mechanics-consistent pathway for next-generation surrogate modeling in structural dynamics. Potential applications include rapid structural assessment, parametric studies, and digital twin frameworks where repeated response evaluations under varying configurations are required.

Speaker



Haifeng Wang

Assistant Professor | Washington State University

MS 049: Mechanics of Soft Synthetic and Biological Materials: Theory, Simulation, and Experiment

4:00 PM – 6:00 PM | Location: CLUB 4-5

Chair(s): Berkin Dortdivanlioglu; Aditya Kumar; Raudel Avila

Moderators



Tingting Xu

Postdoctoral Fellow | Johns Hopkins University

ID 63: Reproducing Biological Catch Bonds in Simple Newtonian Mechanical Systems

4:00 PM – 4:20 PM

Author(s): Kerim C. Dansuk, Bogazici University

Common intuition suggests that tensile force shortens chemical bond lifetimes; however, biological “catch bonds” defy this notion by strengthening under load. While catch bonds are critical for cell adhesion, the physical principles underlying their function in allosteric proteins such as P-selectin, often described by the sliding–rebinding model, have remained disputed, hindering the development of synthetic analogs. In this work, we introduce a simple Newtonian molecular system that reliably reproduces catch bond behavior under thermal excitation, effectively bridging the gap between biological complexity and synthetic design. Our model mimics the allosteric regulation of P-selectin using a coarse-grained, hinged geometry controlled by a “switch” mechanism. In the closed state, the ligand is subjected to a vertical peeling force (low affinity). When an external force ruptures the switch, the system reorients, aligning the force with the binding plane in a sliding configuration (high affinity). We demonstrate that this behavior arises when the switch possesses a wider energy well than the ligand, allowing a soft, low-frequency conformational mode to couple with high-frequency binding dynamics. Our minimalistic system produces a lifetime curve reminiscent of highly complex catch bond protein networks. The significance of this study lies in distilling the complex physics of allostery into accessible mechanical design rules. By validating a mechanism in which force-induced tilting of energy landscapes drives functional transitions, we provide a blueprint for synthetic systems, such as DNA-based catch bonds and nanoparticle networks. These findings pave the way for novel, mechanically active materials that reconcile the trade-off between high tensile strength and dynamic reconfiguration.

Speaker



Kerim Dansuk

Assistant Professor | Bogazici University

ID 250: Homogenization-based micromechanics model for polydomain liquid crystal elastomers

4:20 PM – 4:40 PM

Author(s): Tingting Xu, Johns Hopkins University; Thao D. Nguyen, Johns Hopkins University

Nematic liquid crystal elastomers (LCEs), composed of polymer networks containing rod-like mesogens, display mechanically and thermally responsive deformation linked to the reorientation and ordering of mesogens. Polydomain LCEs crosslinked in the isotropic state consist of an initially isotropic distribution of director orientations. These materials have received increasing attention for soft actuators, programmable morphing structures, and multifunctional devices. Capturing the coupled effects of mesogen alignment, viscoelastic network response, and evolving internal texture in a predictive model remains a significant challenge for polydomain LCEs. Compared with phenomenological descriptions that focus solely on macroscopic behavior, micromechanics-based models can represent domain-level mechanisms of mesogen ordering and provide deeper physical insight.

In this study, we begin from the single-domain scale and employ a finite-deformation thermo-viscoelastic constitutive model that captures mesogen ordering, director rotation, and network viscoelasticity. The director and scalar order parameter are introduced as internal state variables to characterize the evolving mesogen orientation and degree of alignment within each domain. Thermal effects are incorporated through the temperature dependence of the order parameter and the viscoelastic network response. The macroscopic response of the polydomain material is then obtained through a homogenization formulation that integrates the contributions of differently oriented domains and accounts for their mechanical interaction. This multiscale approach predicts the macroscopic response of polydomain LCEs and the evolution of the director distribution and resulting texture under loading. Viscoelastic deformation and director reorientation emerge naturally from the homogenization, establishing a physically grounded link between domain-level physics and bulk material behavior at the representative volume element (RVE) scale.

The proposed homogenized model is evaluated through comparison with experimental observations and full-field numerical simulations. Finite element based homogenization in COMSOL is employed to compute macroscopic stress-strain responses and local heterogeneous strain, stress, and director fields. The model reproduces key characteristics of the polydomain to monodomain transition under mechanical loading and thermally induced actuation and provides microstructural insight into the associated director reorientation. These results demonstrate the capability of the homogenization-based micromechanics framework to capture and interpret the complex nonlinear behavior of polydomain liquid crystal elastomers.

Speaker



Tingting Xu

Postdoctoral Fellow | Johns Hopkins University

ID 428: Simulation of Blood Clots Under Mechanical Loads

4:40 PM – 5:00 PM

Author(s): Morteza Ghiyasi Varzaghan, Arizona State University; Hamidreza Marvi, Arizona State University

Biological tissues such as blood clots exhibit complex mechanical behavior driven by the interaction between their solid fibrin matrix and interstitial fluid. Understanding how these materials deform and rupture under mechanical loading is critical for biomedical applications, including thrombectomy, embolization risk assessment, and device-tissue interaction. However, the soft, fragile nature of clots and their high fluid content make it challenging to experimentally capture internal damage mechanisms. As a result, numerical modeling has emerged as a valuable tool to study clot rupture behavior.

In this study, we simulate the mechanical response and damage evolution of blood clots subjected to mechanical penetration. The clot is modeled as a hyperelastic solid with strain-based damage and failure, implemented in LS-DYNA using an explicit dynamic formulation. Contact between the penetrator and clot is modeled using an automatic surface-to-surface contact algorithm with failure captured through strain-based element erosion. Various loading conditions and penetrator geometries are tested to analyze stress distribution, strain localization, and failure.

The results show strong agreement with experimental observations and demonstrate the model's capability to simulate realistic rupture scenarios. This framework provides insight into clot fracture under clinically relevant loading, supporting the design and evaluation of thrombectomy procedures.

Speaker



Morteza Ghiyasi Varzaghan

Graduate Research Associate | Arizona State University

ID 437: A Hybrid FE-Neural Network Approach for Real-Time Prediction of Hyperelastic Cardiac Valve Mechanics

5:00 PM – 5:20 PM

Author(s): Maedeh Makki, University of California, Riverside; Chung-Hao Lee, University of California, Riverside; Maziar Raissi, University of California, Riverside

Accurate prediction of cardiac valve tissue mechanics is essential for computational biomechanics, device design, and surgical planning. Atrioventricular valve tissues, particularly the tricuspid valve posterior leaflet (TVPL), exhibit strongly nonlinear, anisotropic, and hyperelastic behavior under physiological loading. Traditional finite element (FE) approaches, while accurate, are computationally expensive for real-time applications, while purely data-driven neural networks lack physical consistency and generalization capability. To address these limitations, we present a hybrid physics-informed neural network (FE-NN) framework that integrates a feedforward neural network with a nonlinear FE solver to predict full-field tissue deformation under quasi-static biaxial loading.

Porcine TVPL specimens were subjected to displacement-controlled biaxial mechanical tests along circumferential and radial directions under seven loading ratios ($F_x:F_y = 1:1, 1:0.75, 1:0.5, 1:0.25, 0.75:1, 0.5:1, 0.25:1$) following preconditioning protocols. The tissue response was characterized using a generalized Fung-type hyperelastic model to capture exponential stiffening and material anisotropy. Material parameters were identified from unloading segments of the final two cycles using differential evolution optimization with Weibull-flight mutations, enforcing plane-stress and near-incompressibility constraints to ensure accurate reproduction of experimental stress-strain behavior.

The framework employs a solver-in-the-loop training strategy where a six-layer feedforward neural network with 128 neurons per layer predicts pointwise displacements as functions of spatial coordinates, time, and loading ratio. These predictions serve as trial fields for the FE solver, which enforces equilibrium through Newton-Raphson iterations based on the weak form of quasi-static hyperelasticity. The FE-corrected displacement fields provide physics-consistent training targets, enabling the network to learn displacement patterns satisfying the governing equations without explicit PDE residual terms or empirical loss weighting strategies. This design avoids convergence issues and spectral bias commonly encountered in conventional PINNs while maintaining compatibility with commercial FE codes.

Performance was evaluated using leave-one-ratio-out cross-validation across six case studies, including four in-distribution (ID) and two out-of-distribution (OOD) scenarios. For spatial displacement predictions at peak load, the framework achieved mean absolute percentage errors (MAPE) below 15% for both components across all cases. Temporal tracking demonstrated exceptional correlation for in-distribution cases, with R^2 reaching 0.9969 for U_1 and 0.9868 for U_2 , while OOD cases maintained $R^2 > 0.85$, confirming robust extrapolation to unseen equibiaxial loading. Volume-averaged stress predictions exhibited R^2 up to 0.9926, with four of six cases exceeding 0.94. Critically, stretch ratio validation in a central 4×4 element window yielded MAPE below 1.4% and maximum errors under 2.7%, demonstrating exceptional accuracy in capturing local deformation gradients. Derived stress predictions maintained MAPE below 7.8%, with maximum errors below 37%. The framework accurately reproduced characteristic J-shaped stress-stretch curves across both loading and unloading phases, with close overlap between FE-NN predictions and FE reference solutions across all case studies.

The hybrid FE-NN framework successfully learns constitutive behavior from experimental data while maintaining physical consistency through embedded FE enforcement, providing a computationally efficient surrogate suitable for parametric studies, optimization, and potential real-time cardiovascular biomechanics applications.

Speaker



Maedeh Makki

PhD Student | University of California, Riverside

ID 610: Smart flexible minimally invasive probe for electrophysiological signal monitoring and diagnosis

5:20 PM – 5:40 PM

Author(s): Aishwarya Pravin Kakade, University of Colorado Boulder; Jianliang Xiao, University of Colorado Boulder

Electromyography (EMG) is a vital diagnostic tool for neuromuscular disorder; however, existing EMG systems rely largely on surface electrodes, invasive needle electrodes, and probes that are predominantly rigid and mechanically mismatched with soft biological tissues. Surface electrodes often struggle to establish reliable contact with the skin, cannot accommodate tissue deformation, and lack biocompatibility for in-body use. Needle electrodes, in contrast, are invasive, painful, and can cause tissue damage. Moreover, in-body EMG probes are rigid and stiff, preventing them from conforming to complex anatomical geometries, and also causing discomfort during insertion and use, and limiting access to deep muscle activity. Once inserted, probe motion caused by patient movement often leads to unstable electrode-tissue contact and inconsistent signal quality.

To address these limitations, we developed a lightweight, biocompatible, self-deploying intraluminal high-density surface EMG (HD-sEMG) probe for minimally invasive electrophysiological monitoring inside the body. The device leverages principles of thin-film mechanics, soft materials, and smart structures, featuring a multilayer thin-film architecture that minimizes flexural rigidity. It comprises a soft, flexible shape-memory polymer (SMP) substrate, biocompatible Ag/AgCl electrodes, and a polyimide insulating layer, resulting in an overall probe thickness of less than 1 mm.

The SMP primarily used in this research is an acrylate-based network polymer. This SMP is well suited for flexible electronics applications because its glass transition temperature is around 40 °C, close to human body temperature (37 °C), allowing shape changes to be easily triggered by environmental or Joule heating stimulus. In addition, the SMP shows a large change in elastic modulus across this transition, increasing from ~3 MPa to ~1.5 GPa when cooled. SMPs exhibit a thermomechanical shape memory effect (SME) that allows them to recover a predefined shape in response to external stimuli such as temperature. Leveraging this property, the SMP-based probe is programmed into a compact, rolled configuration for insertion. Upon exposure to body temperature, the probe autonomously expands to its original shape, conforming to surrounding tissue and ensuring reliable electrode contact.

This research is expected to demonstrate that, once inserted into the body, the probe will autonomously self-deploy, establish stable and conformal contact with surrounding tissues, reliably sense electrophysiological signals, and transmit the acquired data to an OpenBCI biosensing microcontroller for analysis. By overcoming the limitations of conventional EMG systems, this probe allows for minimally invasive insertion while maintaining reliable tissue contact and stable probe positioning during patient movement and eliminates the need for custom manufacturing. We hope that our findings will ultimately contribute to the development of next-generation smart flexible shape memory electronics for electrophysiological signal monitoring and diagnosis.

Speaker



Aishwarya Kakade

PhD student | University of Colorado Boulder

ID 73: Characterization of Multifunctional Properties of Biofidelic Solid-Liquid Composites

5:40 PM – 6:00 PM

Author(s): Vinu Unnikrishnan, West Texas A&M University; Karthik Kundapur, West Texas A&M University; Francis Nwokwu, West Texas A&M University; Oyshrojo Talukder, West Texas A&M University

Solid-liquid composites (SLCs) materials in general have a liquid phase enclosed in a solid phase and have potentially unique multi-functional applications in various advanced industries. These novel composite materials are likely to replace conventional composite materials in advanced applications such as wearable devices and safety gears, due to their unique thermal and electrical properties, and excellent energy absorption characteristics. In addition, specific biofidelic SLCs can exhibit mechanical properties similar to human or animal skin or tissues. The advantage of such a composite system is that the ensuing composite is not only biofidelic but can be used to study human or animal pathological conditions like seroma or cysts. In this work, dilute SLC systems are fabricated using commercial grade silicone (Smoothon Ecoflex 00-30), as the solid phase and laboratory grade Glycerin as the liquid phase. A novel methodology was developed to fabricate the biofidelic SLC by precisely controlling the volume of the liquid phase. This fabrication process ensures creation of a dilute SLC with a precise volume fraction of the liquid phase. The elasto-mechanical properties of the biofidelic SLCs are determined experimentally for various volume fractions of the liquid phase, using uni-axial testing, and are compared with the properties of biofidelic soft composite materials from literature. In addition, experimental studies to characterize the multifunctional properties of various volume fractions and sizes of the SLCs, will be discussed in this presentation. These experimental studies are then used in various micromechanical models to characterize their effective multifunctional properties. The major significance of this study lies in the characterization of multifunctional properties of biofidelic soft composites and its relationship with varying volume fraction of the liquid phase.

MS 047: Mechanics and Data-Driven Innovations in Road Paving Materials

4:00 PM – 6:00 PM | Location: CASE E230

Chair(s): Augusto Cannone Falchetto; Ramez Hajj

Moderators



Ramez Hajj

Assistant Professor | University of Illinois Urbana-Champaign

ID 934: Moisture Susceptibility and Meso-Structural Evolution of High-RAP Asphalt Mixtures after Multiple Recycling Cycles

4:00 PM – 4:20 PM

Author(s): Yuxuan Sun, Aalto University; Fan Zhang, Aalto University; Di Wang, University of Ottawa; Weiwei Lin, Aalto University; Augusto Cannone Falchetto, University of Padova

Moisture damage remains a primary cause of premature deterioration in asphalt pavements by weakening binder–aggregate bonding, accelerating stripping, and promoting microcracking under traffic. While the use of high reclaimed asphalt pavement (RAP) content is increasingly adopted to reduce environmental burdens, the durability of such mixtures under repeated recycling and rejuvenation remains poorly established. This study investigates the mechanical response and meso-structural evolution of a dense-graded asphalt mixture incorporating 60% RAP over five successive recycling cycles, each supported by a bio-oil rejuvenator. A multi-scale experimental program was implemented to link physicochemical indicators to mixture-scale performance and internal structure. Binder–aggregate interactions were quantified through surface free energy (SFE) analysis, focusing on adhesion indices and water affinity. Moisture resistance at the mixture level was assessed using the indirect tensile strength ratio (ITSR). Mechanical degradation under moisture-assisted conditioning was evaluated using dynamic modulus testing and the moisture-induced stress tester (MIST). To capture damage-relevant structural changes, X-ray computed tomography (CT) scanning was performed to characterize void content, connectivity, and morphological coarsening. Finally, principal component analysis (PCA) was employed to integrate the dataset and identify dominant deterioration drivers across recycling stages. Results indicate that progressive recycling reduced interfacial adhesion and increased moisture affinity, evidencing cumulative binder aging and diminished compatibility at the binder–aggregate interface. Consistently, ITSR remained above 80% through the third cycle but decreased markedly in later cycles, accompanied by an apparent loss of stiffness under dynamic moisture conditioning. CT observations revealed that the first recycling cycle slightly enhanced compactness, whereas subsequent recycling cycles promoted a coarser, more connected air-void network, facilitating moisture transport pathways. PCA highlighted a transition in governing mechanisms: adhesion-related factors were more influential in early cycles, but moisture intrusion and pore-network connectivity dominated deterioration beyond the third cycle. Overall, the findings suggest that satisfactory water resistance can be preserved up to approximately two recycling cycles, while durability declines sharply thereafter due to compounded binder aging, interfacial degradation, and void-network coarsening.

Speaker



Augusto Cannone Falchetto

University of Padova

ID 557: Hybrid Machine Learning and Mechanistic Back Calculation Approach for Predicting Surface Layer Modulus of Rigid Pavements Using LTPP Data

4:20 PM – 4:40 PM

Author(s): Usama Asif, University of Maryland; Osama Aljarrah, University of Maryland; Jongwan Eun, University of Maryland

This paper presents a hybrid mechanistic and machine learning framework for predicting the surface-layer elastic modulus of rigid pavements using multi-source Long-Term Pavement Performance (LTPP) data. Most existing modulus-prediction studies emphasize asphalt materials or rely solely on Falling Weight Deflectometer (FWD) back-calculation, with limited application to Portland cement concrete (PCC) and limited consideration of broader structural, climatic, traffic, and condition indicators. To address this gap, a dataset of 1269 PCC sections from four U.S. climate regions was considered, incorporating structural, environmental, traffic and age, and distress variables. Three machine learning models, including an artificial neural network (ANN), a random forest (RF), and XGBoost, were trained and tuned using a 70/30 train–test split with hyperparameter optimization performed through Grid Search CV with 5-fold cross-validation. Model performance was evaluated using RMSE, MAE, MAPE, RRMSE, and R^2 . RF achieved the highest predictive accuracy with R^2 values of approximately 0.93 for training and 0.87 for testing, while XGBoost performed comparably, and ANN showed substantially lower predictive accuracy. Model interpretability was assessed using SHapley additive explanations (SHAP), which identified PCC thickness, annual freeze–thaw exposure, and resilient modulus as the most influential predictors, with climatic and traffic indicators contributing moderately and distress measures contributing minimally. Mechanistic benchmarking was conducted using the Federal Aviation Administration Back-calculation of Asphalt Layer Moduli (BAKFAA) applied to LTPP FWD basins. RF predictions aligned closely with LTPP actual moduli, whereas BAKFAA generated consistently higher estimates for a few sections. The results indicate that ensemble learning models trained on multi-dimensional LTPP data can complement or, in some cases, partially substitute mechanistic back-calculation by providing accurate, interpretable, and computationally efficient modulus estimates. This hybrid methodology supports improved pavement evaluation, rehabilitation planning, and long-term asset management for PCC pavements.

Speaker



Jongwan Eun

Associate Professor | University of Maryland

ID 104: A Sustainable Method to Recycle Waste Plastic as Fiber into Asphalt Mixes

4:40 PM – 5:00 PM

Author(s): Daeui Hong, Liberty University; Songsu Son, Liberty University

This study proposes a novel approach to benefit the environment and enhance the cracking resistance of asphalt mixes by repurposing waste plastic bottles as reinforcing fibers. Since there are over fifty million tons of waste plastic produced annually in the United States, and this waste plastic is mostly disposed of in landfills and incineration, but less than 6% of it is recycled. It is necessary to find sustainable ways to reuse waste plastic as the usage of plastic increases. Recent studies have explored wet and dry processes, which incorporate waste plastic into the asphalt mixtures. However, these processes require a melting stage, which may cause environmental and health risks from toxic fume emissions, and they cause detrimental effects on asphalt binder, such as phase segregation issues during long-term storage. Therefore, this study aims to develop a new method using waste plastics that also improves asphalt performance. This method is recycling polyethylene terephthalate (PET) plastic bottles by mechanically fabricating them into fibers to incorporate with asphalt mixtures where they can play a role as a reinforcing skeleton. This fiber structure was expected to improve crack resistance by delaying crack propagation. To evaluate the performance of cracking resistance of PET plastic fiber-reinforced asphalt mixture, fracture testing was conducted using the standard method AASHTO T393. Several experimental conditions were examined varying dimensions and dosage of fibers and temperatures ranging from ambient to subzero conditions. The experimental results demonstrated improvements in fracture energy in most of the conditions, especially fracture energy increased by 66.4% under low temperature conditions. The fibers that were in the cracking surface behaved in two different patterns; fiber pull-out predominantly occurred at ambient temperature, and fiber breakage occurred at lower temperatures. This study establishes the feasibility of mechanically processed PET waste fibers as asphalt reinforcement, providing a potential solution for waste plastic while improving pavement's cracking resistance. The findings in this study also suggest that this approach could offer a more sustainable alternative to conventional repurposing methods of waste plastic in asphalt pavements while potentially reducing costs and environmental impact. To complement this study, additional experimental testing will be included for the cyclic fatigue test using the standard method AASHTO TP133 to understand the behavior of cracking damage under repeated loading. Further studies may focus on the characterization of the fiber's bonding mechanisms at varying temperatures and evaluating production feasibility using Life Cycle Assessment.

Keywords: Polyethylene Terephthalate (PET) Plastics, Waste Plastic, Fibers in Asphalts, Cracking Resistance, Cracking Damage, Fracture Energy

Speaker



Daeui Hong

PhD Student | Liberty University

ID 120: Probabilistic Investigation of TSD-induced Critical Strains in Multi-layer Pavement Systems

5:00 PM – 5:20 PM

Author(s): Ze Zhou Wang, University of Cambridge; Zhaojie Sun, University of Cambridge; Bachar Hakim, AECOM; Abir Al-Tabbaa, University of Cambridge

The Traffic Speed Deflectometer (TSD) is a promising technology for the continuous structural health monitoring of pavements. Its ability to continuously measure load-induced pavement responses without disrupting traffic has prompted many authorities worldwide to explore its potential in network-level pavement structural evaluation. On the other hand, rutting is a typical pavement distress. According to the Mechanistic-Empirical Pavement Design Guide (MEPDG), rutting depth is governed by strains at multiple critical depths within the pavement structure. Since strains are typically measured using embedded sensors, which cannot be conveniently implemented at the network-level, this study investigates the feasibility of deriving these strain responses directly from TSD surface measurement for mechanistic analysis. To achieve this, a probabilistic investigation of TSD-induced strains was conducted. In this study, a physics-based simulator, PaveMove, was developed based on the Spectral Element Method (SEM) to model the mechanical responses of pavements under TSD dynamic loading. In addition to modelling pavement surface deflections or deflection slopes, PaveMove can directly simulate longitudinal, transverse and vertical strains throughout the multi-layer system. Following a typical four-layer pavement system, this study focused on the strains at the surface layer (e.g., top and bottom) and the subgrade interface. First, a comprehensive probabilistic parametric analysis was conducted to assess the sensitivity of these TSD-induced strains to the modulus of the four layers. Second, the uncertainties associated with the modulus of these layers were propagated using the Monte-Carlo simulation to understand the resulting uncertainties in pavement strains at these critical locations within a multi-layer system. A comparison with conventional deterministic analyses was further conducted to highlight the importance in considering material uncertainties in understanding pavement behavior. The results indicated the non-neglecting effects of uncertainties in material properties, wheel configurations, and the complex wheel-pavement interactions on pavement strain responses. These understandings provide instrumental information for the subsequent prediction of rutting distresses. Finally, to facilitate practical implementation, machine learning models were developed to correlate TSD-derived parameters to pavement strains at these critical locations. This model provides an effective tool to expand the engineering information that can be derived from TSD measurements, ultimately advancing mechanistic pavement management and rutting prediction at the network level.

MS 061: Topology Optimization: from Algorithmic Developments to Applications

4:00 PM – 6:00 PM | Location: CASE E240

Chair(s): Mazdak Tootkaboni; Chuan Luo; Josephine Carstensen; Shelly Zhang; James Guest

Moderators



Josephine carstensen

Associate Professor | MIT

ID 652: Level-Set Topology Optimization with XIGA in Finite-Strain Contact Problems

4:00 PM – 4:20 PM

Author(s): Anna Chotzalli, University of Colorado Boulder; Kurt Maute, University of Colorado Boulder

The level-set method (LSM) in topology optimization, combined with eXtended Isogeometric Analysis (XIGA), is a promising approach to finding the optimal shape of structures. This combination is especially advantageous for problems involving contact mechanics, where a sharp and accurate representation of evolving boundaries is essential for reliably predicting mechanical responses. A design optimization framework for structures undergoing contact under finite deformations is presented in this work, with a focus on multi-material configurations and large sliding interactions. Level-set functions are used to describe external boundaries and material interfaces, enabling the treatment of multi-material designs. The structural response is modeled with a finite-strain, hyperelastic formulation that takes into account nonlinearities in both the geometry and the material. Contact detection between higher-order geometric facets is performed using a ray-tracing method, which robustly tracks evolving surface orientations and overlapping regions under large deformations and relative motion. The contact constraints are enforced using a mortar-based formulation, ensuring a consistent and accurate transfer of contact tractions between nonconforming, higher-order discretizations. An adjoint-based sensitivity formulation is used to capture the strong coupling between finite-deformation kinematics, frictional mortar contact constraints, and the evolving design geometry, enabling robust gradient-based optimization in the presence of large sliding and nonlinear contact interactions. The optimization problems focus on enhancing overall stiffness and adjusting contact stresses while imposing constraints on feature size and curvature. These problems are solved using a nonlinear programming method, with the shape sensitivities computed via a semi-analytical version of the adjoint method. The effectiveness of the proposed framework for multi-material designs involving frictionless and frictional contact is demonstrated by numerical examples in both two and three dimensions, including nonlinear Hertzian and large-strain contact scenarios, demonstrating its capability to handle significant deformations and complex contact regions. The results highlight the significance of high-order shape descriptions, the importance of the contact formulation in an immersed setting, and the necessity of feature size and curvature constraints.

Speaker



Anna Chotzalli

University of Colorado Boulder

ID 654: A comparison of methods to compute geometric measures for gradient-based level-set topology optimization

4:20 PM – 4:40 PM

Author(s): Brendan Chong, University of Colorado Boulder; Kurt Maute, University of Colorado Boulder

Topology optimization aims to find the optimal shape of bodies such that some performance measure is maximized, accounting for design constraints. This work focuses on level set topology optimization and related approaches that use an explicit shape description. These approaches offer distinct advantages over traditional, density-based methods, especially a clearly defined structural shape throughout the optimization process, which facilitates the enforcement of boundary and interface conditions.

Typically, objectives and constraints depend on the system response. In addition, geometric measures such as curvature and shape diameter are commonly employed to improve the manufacturability of topology-optimized structures. The structural shape also needs to be controlled in the optimization process to suppress the emergence of artifacts due to unmodeled and/or insufficiently resolved physical phenomena. However, existing methods for computing these measures often lack robustness, particularly for complex geometry configurations or low-quality meshes. As a result, their use in gradient-based topology optimization is unreliable and further complicated by the requirement for smooth, well-defined sensitivities.

This work systematically characterizes several approaches for computing curvature and feature size in level set topology optimization and identifies the regimes in which each method is most effective. The methods are evaluated with respect to mesh dependence and robustness to local geometric features. In addition, we assess how different regularization techniques affect both the interpretability of the geometric measures and the quality of the resulting optimized geometries. The impact of each approach is studied within the context of a linear elastic compliance minimization problem. Finally, to account for potential interactions between geometric regularity and optimization strategy, both GCMMA and L-BFGS optimization algorithms are considered.

Speaker



Brendan Chong

Graduate Student | University of Colorado Boulder

ID 666: Optimizing for Connections: How Surrounding Structures Experimentally Impact the Performance of Interlocking Joints

4:40 PM – 5:00 PM

Author(s): Inés Ortea Varela, Massachusetts Institute of Technology; Zane Schemmer, Massachusetts Institute of Technology; Anthony Koh, Massachusetts Institute of Technology; Josephine Carstensen, Massachusetts Institute of Technology

With the demand for new and refurbished infrastructure on the rise, civil engineers are beginning to turn towards optimization techniques to accomplish jobs more efficiently. One such method that shows promise for the field is topology optimization. Topology optimization is a computational design tool that mathematically determines where to place structural material to minimize or maximize an objective function while respecting user defined constraints. Historically, the implementation of topology optimized results in civil infrastructure has been limited because designs are not always geometric and can make their construction difficult. With advancements in 3D printing of metals and cementitious materials, however, complex designs are becoming more trivial to fabricate.

While 3D printing makes the creation of complex structures easier, there are still difficulties when scaling this technology to larger civil structures. Some of the current issues include limitations on the build plate size and the weak behavior at the interface between connecting components. To address these concerns, some researchers are taking inspiration from one of the oldest connection techniques: interlocking joints. Interlocking joints allow different structural members to slot together and connect without additional fasteners or adhesives. They are less common in modern structures because long prismatic members make fasteners economical and straightforward to design. Yet the design of fasteners connecting numerous smaller members with complex geometric shapes can become cumbersome. Thus, the use of interlocking joints can make it easier to extend optimized designs beyond the dimensions of a build plate. Research has also shown that interlocking joints can improve the strength at interfaces between components composed of different materials.

What current research is not studying as intensively, however, is how the surrounding structure impacts the mechanics of the interlocking joint itself. If the structure surrounding an interlocking joint adversely impacts its performance, the role of interlocking joints in creating optimized structures could be diminished. This work experimentally examines how a beam subjected to three-point bending, connected by a single central Mortised Rabbeted Oblique (MRO), could be impacted by different end topologies and lengths. The end topologies are optimized for varying volume fractions, and the lengths are adjusted to span between short and long beams. Results show that these different parameters can heavily influence the failure mode of a specimen.

Speaker



Zane Schemmer

PhD Candidate | MIT

ID 669: 3D Truss-Continuum Topology Optimization of Reinforced Concrete Floor with Demolding Constraint

5:00 PM – 5:20 PM

Author(s): Pitipat Wongsittikan, MIT; Jackson Jewett, MIT; Josephine Carstensen, MIT

This work presents a framework for designing ready-to-fabricate reinforced concrete (RC) floors using a topology optimization method with a hybrid truss-continuum mesh and an asymmetric material model. As reinforced concrete is the main contributor to global CO2 emission, strategies to reduce embodied carbon in structures are needed (GlobalABC, 2020). Topology optimization has shown to be able to reduce material used in RC structures by 40% while keeping the same structural performance (Jewett and Carstensen, 2024; Amir, 2013). However, topology optimization designs are usually complicated which makes them challenging to fabricate using construction industry's preferred method, casting and demolding. While topology optimization with a demolding constraint exists (Vatanabe et al., 2016), it has only been applied to single material structures that are discretized with continuum elements. Previous works have not included reinforcing members that are e.g., described by a truss discretization. This shortcoming is addressed in the current work that uses a combination of 3D continuum and truss elements. The continuum elements are used to describe the concrete phase of the design and the truss elements represent the steel reinforcement. An extended formulation of the demolding constraint is formulated such that both the continuum part of the structure as well as the reinforcing forcing elements can be removed from a mold if fabricated with conventional casting. Formulating the framework in 3D enables us to work on floor structures, which are considered to have high embodied carbon in buildings (Huberman et al., 2015). It also enables the design of more varieties of structure shapes, loads, and support conditions. The framework does not only enable us to achieve ready-to-fabricate topology optimized RC designs, but it also reveals the trade-off between manufacturability and performance.

Speaker



Pitipat Wongsittikan

PhD Student | MIT

ID 896: Leveraging Human Knowledge to Improve Multi-Material Topology Optimization

5:20 PM – 5:40 PM

Author(s): Jacqueline Orr, MIT; Josephine Carstensen, MIT

Recent decades have seen rapid advances in Additive Manufacturing (AM) technologies, including the development of many types of multi-material 3D printers. Topology Optimization (TO) allows design engineers to leverage these manufacturing process improvements that enable the fabrication of customized designs with much higher levels of complexity. This includes the possibility to design for multi-material 3D printing. Although the literature on multi-material TO is rich, relatively few works have included considerations of the multi-material interface. Especially for desktop printers, completely omitting the consideration of the interface mechanics can be detrimental to the performance of a printed design specimen. However, interface mechanics is highly nonlinear, and its explicit inclusion in TO therefore severely affects both the runtime and the hyperparameter tuning required for a design problem. Since the design time is a known barrier for widespread adoption of TO, this work takes an alternative approach to infusing improvements of multi-material interfaces. Using a Human-in-the-Loop approach, the TO problem is paused such that the design engineer's experience can be an interactive, integrated part of the otherwise automated design process [1], [2]. In this work, the designer is enabled to add mechanical interlocks that are known to improve the behavior of multi-material interfaces. The new design approach is applied to several TO benchmark examples and demonstrated to improve the interface between the materials.

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Speaker



Josephine carstensen

Associate Professor | MIT

ID L2: Simultaneous Optimization of Topology and Local Material for Functionally Graded Structures

5:40 PM – 6:00 PM

Functionally graded structures are a class of structures with smoothly varying material properties. They have been shown to outperform structures and components made of single material, or only a few distinct materials, for many design problems [1,2]. Interest in functional grading has grown in recent years due to advancements in manufacturing capabilities. While previously focused on polymers and composites, new metallic additive manufacturing processes are enabling the development of graded properties in metallic systems, while also creating new challenges.

The increased design freedom associated with functionally graded structures aligns well with topology optimization-driven design processes, which optimize the distribution of materials across a design domain. In this study, the authors will present recent advancements in topology optimization for functional grading, including manufacturing constraints and simultaneous selection of feedstock materials, graded properties, and structural topology in three dimensions. The overarching computational framework will be discussed, along with limitations, challenges, and future work.

Key Words: Topology optimization, Functionally Graded Structures, Multi-Material Design

REFERENCES

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Speaker



Gabriel Dreisbach

Johns Hopkins University

MS 053: Tensegrity – Form finding, analysis, mechanical behaviour, control, and design of tensegrity and tensegrity-like systems

4:00 PM – 6:00 PM | Location: KTCH 1B87

Chair(s): Landolf Rhode-Barbarigos; Muhao Chen; Ajay Harish

Moderators



Muhao Chen

Assistant Professor | University of Houston

ID 550: Preliminary investigations on a mobile tensegrity robot with shape transformation possibility between a Tetrahedron and an Octahedron

4:00 PM – 4:20 PM

Author(s): Lukas Lehmann, OTH Regensburg; Sumit Kumar, University of Miami; Subhamoy Sen, Indian Institute of Technology Mandi; Valter Böhm, OTH Regensburg; Landolf Rhode-Barbarigos, University of Miami

This work investigates a tensegrity structure composed of two rigid, right-angled compressed members, each formed by two struts of length a , which are nested together with their internal angles. These are indirectly connected to each other by nine prestressed tensioned members, which are attached to their ends and corner points. This work describes the shape-transformation possibility of this structure between a tetrahedron and an octahedron. The transformation is realized through the actuation of a single tensioned member connecting the vertices of the compressed members. The structure undergoes two distinct phases: initially, it forms a perfect tetrahedron when the tensioned member length $L = 2\sqrt{a^2/2} - a$. By reducing the prestress of this member through external actuating, the distance increases while the outer structure remains tetrahedral until $L = \sqrt{a^2/2}$ is reached. Beyond this point, the vertices of the compressed members extend outward, creating four new faces and forming an octahedron, which reaches its perfect configuration at $L = 2\sqrt{a^2/2}$.

Tilting locomotion can be achieved either via shape-shifting by modifying the lengths of selected members or by using additional actuated mechanisms (e.g. bistable mechanisms) at the ends and vertices of the struts to provide impulsive tipping. In both the perfect tetrahedral and octahedral configurations, the outer faces remain equilateral triangles. However, those of the octahedron are 0.866 times smaller. Consequently, qualitatively similar tilting locomotion patterns are possible in these configurations, but different positions can be reached. In intermediate configurations the outer faces are non-equilateral triangles of varying sizes, resulting in distinct locomotion patterns. By combining tilting locomotion with symmetric shape transformation, the structure can reach any position on a plane. In general, the octahedron is physically favored for tilting locomotion due to a lower required tipping angle of 35.265° , compared to 54.735° for the tetrahedron.

The transformation between the tetrahedral and octahedral shape is not only applicable for locomotion but also allows switching between stiff and compliant configurations. For example, as a planetary exploration robot, the tetrahedral configuration can absorb impacts during a drop, after which the structure can transform and move with increased compliance, protecting sensitive payloads. Spatial flexibility ellipsoid analysis, simulating a drop test with a centrally fixed load, shows that the tetrahedron is stiffer and thus better suited for payload protection whereas the octahedron configuration shows enhanced and more uniform compliance.

All simulations were performed using a geometric nonlinear, static finite element analysis in MATLAB and qualitatively validated with an initial demonstrator. Future work will include dynamic analysis of the locomotion process and the development of a fully functional prototype with active control.

Speaker



Lukas Lehmann

PhD Student | OTH Regensburg, Germany

ID 664: Tensegrity Free-Free Beam: Design and Analysis

4:20 PM – 4:40 PM

Author(s): Benjamin Ingalls, Texas A&M University; Manoranjan Majji, Texas A&M University

The free-free (unsupported) beam is a fundamental structural and dynamic problem for the aerospace field of study. They are often seen in aircraft wings, unconstrained structures on spacecraft, or even in robotic manipulators. The study of these structures includes classic strength and stiffness metrics, but is dominated by the unique modal characteristics that this boundary condition produces. Because of this, a structure with tunable modal characteristics is desirable.

This study aims to investigate the dynamic behavior, stiffness, and load-bearing performance of tensegrity free-free beams. Tensegrity structures, made of purely tensile and compressive members held in equilibrium, have been thoroughly studied for simply supported and cantilever loading conditions.[2,3] However, little research has been done on effective topologies for free-free beam conditions. This research intends to provide a family of tensegrity structures designed for the free-free loading condition. These structures will take inspiration from previously designed simply-supported, cantilever, and truss structures.[1] They will utilize the mass efficiency and tunable stiffness of tensegrity structures, as compared to their continuum counterparts, to produce lightweight structures with modal characteristics advantageous to the applications. Multiple tensegrity topologies will be studied, highlighting the strengths and weaknesses of each depending on the design parameters.

This work will also develop a modeling framework using multibody dynamics and structural mechanics to characterise the tensegrity beam in free-free motion. Modal analysis will identify natural frequencies and mode shapes as well as develop an understanding of how pre-stress affects these attributes.

By providing a comparison between tensegrity and continuum beams in free-free conditions, this work will provide a foundation for using tensegrity in applications where mass and modal control are paramount, such as aircraft or spacecraft applications. It will be shown that these tensegrity structures provide a lightweight frame with tunable stiffness and modal characteristics. These findings lay the groundwork for future optimization and experimental validation of novel tensegrity structures.

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Speaker



Benjamin Ingalls

PhD Student | Texas A&M University

ID 723: Generation and Transformation of Multistate Tensegrity Systems via Cellular Morphogenesis

4:40 PM – 5:00 PM

Author(s): Sumit Kumar, University of Miami; Landolf Rhode-Barbarigos, University of Miami

This work introduces a framework for the generation and transformation of geometrically diverse multicellular tensegrity structures from a single fundamental building block. A minimal canonical tensegrity cell serves as the fundamental building block, with a fixed topology and only one self-stress state. Its force-compatible connectivity allows it to act as a mechanical and structural basis for complex systems. When multiple cells merge through cellular morphogenesis, they result in multicellular tensegrity that expands the space of admissible self-stress states. This multiplicity arises from the superposition and redundancy of the cellular self-stress modes, creating internally determinate multistate systems. Crucially, the number and nature of these global self-stress modes can be determined by the assembly pattern, not by the specific geometry. This establishes a formal connection between the self-stress spaces of various morphologies such as grid and circular through systematic geometric decomposition and recombination, adhering to additional geometric constraints such as rotational symmetry and closure. These constraints modify the admissible self-stress space, typically reducing its dimensionality, thereby confirming a structural equivalence between morphological tensegrity configurations. Ultimately, the framework facilitates a systematic exploration of design variations between various tensegrity morphologies. These configurations showcase unique self-stress distributions and deformation modes, enabling customized mechanical responses like anisotropy and localized deformation. This structured approach allows for the creation of tensegrity systems with programmable irregularities, integrating lattice-level order with the adaptive functionality typical of biological structures.

Speaker



Sumit Kumar

Mr. | University of Miami

ID 792: Invariant dual mechanics of tensegrity and origami

5:00 PM – 5:20 PM

Author(s): Xiangxin Dang, Princeton University; Glaucio Paulino, Princeton University

From termite nests to cancellous bone, irregular structures are ubiquitous in nature but difficult to harness in artificial systems requiring target mechanical properties. Beyond existing bio-inspired or computational efforts, we propose an optimization-free approach that directly generates irregular structures by applying mathematical transformations to regular ones and preserves their mechanical stability (or instability) throughout the process. Specifically, we focus on two engineering structures that are both artistic and functional—tensegrity and origami—and demonstrate a mathematical duality relationship between the states of self-stress of tensegrity and the infinitesimal mechanisms of origami. More importantly, we show that this duality remains invariant under nondegenerate linear transformations applied to the tensegrity and origami configurations. Furthermore, we establish that the stability property of tensegrity, particularly super-stability, is preserved under such transformations. We apply the invariant duality theory to tensegrity and origami structures with prismatic and polyhedral geometries, illustrating its broad applicability. This invariant dual mechanics opens a new avenue for the fast generation of irregular, three-dimensional structures and architected materials.

Speaker



Xiangxin Dang

Postdoctoral Research associate | Princeton University

ID 980: Morphological Design and Parametric Characterization of Core-Expander Tensegrity Structures

5:20 PM – 5:40 PM

Author(s): Muhao Chen, University of Houston; Aguinardo Fraddosio, Polytechnic University of Bari; Andrea Micheletti, University of Rome Tor Vergata; Gaetano Pavone, Polytechnic University of Bari; Mario Daniele Piccioni, Polytechnic University of Bari

V-Expander tensegrity structures are lightweight and easily assembled modular structures originally put forward by Raducanu and Motro that, owing to their versatility, have been investigated regarding their morphology, load-carrying properties, and static and dynamic actuation. This study presents a novel tensegrity family, named Core-Expander, obtained as a morphological variation of the V-Expander family. Core-Expanders are Class-3 tensegrities that enable a large internal space of the tensegrity cell to be utilized while preserving the features of modularity, achirality, and absence of internal mechanisms that are typical of V-Expanders. The procedure to design the self-stress state of the Core-Expander cells, accounting for the unilateral behavior of the elements and the symmetry properties of the cell, is described. Such a procedure was employed to perform a parametric analysis in terms of the axial and radial aspect ratios and the complexity parameter. The findings of this work can be applied to the design of single cells and modular assemblies with actuation and sensing capabilities and enhanced payload capacity.

Speaker



Muhao Chen

Assistant Professor | University of Houston

ID 1006: Data-Driven Control of Tensegrity Robots for Reference Tracking and Obstacle Avoidance

5:40 PM – 6:00 PM

Author(s): Muhao Chen, University of Houston

Tensegrity robots possess unique advantages in lightweight construction, compliance, and deployability, but their strongly coupled nonlinear dynamics and limited actuation make reliable motion control in dynamic environments challenging. This paper presents a reinforcement learning–based control framework for tensegrity robots that simultaneously addresses dynamic reference tracking and obstacle avoidance. The tensegrity system is treated as a black-box nonlinear plant, driven by actuator internal forces, while task-specific observations are constructed from free-node states and auxiliary variables encoding tracking and obstacle proximity. Local linear models are identified along nominal trajectories using perturbation-based system identification, enabling iterative control refinement through an iLQR-style backward–forward optimization without requiring explicit analytical linearization or preplanned trajectories. The proposed approach autonomously resolves feasibility discontinuities and balances competing objectives through cost-function design. Numerical studies demonstrate effective reference tracking and robust obstacle avoidance under time-varying conditions, highlighting the method’s adaptability to complex, high-dimensional tensegrity systems. The framework provides a solution for safe and precise control of compliant robotic structures operating in uncertain environments.

Speaker



Muhao Chen

Assistant Professor | University of Houston

MS 065: Advanced Computational Methods for Uncertainty Propagation and Risk Assessment in Engineering

4:00 PM – 6:00 PM | Location: GUGG 205

Chair(s): Liuyun Xu; Meng-Ze Lyu; Seymour Spence; Jian-Bing Chen; Michael Beer

Moderatorss



Liuyun Xu

Assistant Professor | The University of Texas at Arlington



Meng-Ze Lyu

Research Fellow | Leibniz University Hannover

ID 147: Decoupled multi-probability density evolution method for uncertainty propagation and risk assessment in nonlinear engineering systems

4:00 PM – 4:20 PM

Author(s): Meng-Ze Lyu, Leibniz University Hannover; De-Cheng Feng, Southeast University; Jian-Bing Chen, Tongji University; Michael Beer, Leibniz University Hannover; Jie Li, Tongji University

Accurate uncertainty propagation and risk assessment in nonlinear stochastic dynamical systems are fundamentally dependent on the efficient determination of joint probability density functions (PDFs) of multiple response quantities. However, for high-dimensional systems with strong nonlinearity and complex probabilistic dependence, the probability density evolution equations are typically high-dimensional, strongly coupled, and computationally prohibitive. This challenge severely limits the practical application of full-probabilistic methods in engineering risk analysis. This paper presents a unified decoupled multi-probability density evolution method (M-PDEM) that significantly alleviates the curse of dimensionality in joint PDF computation. The method is developed based on the random event description for the principle of preservation of probability. Instead of solving an m-dimensional generalized density evolution equation (GDEE) for m response processes, the proposed approach transforms the coupled system into a set of m one-dimensional GDEEs. As a result, the computational cost grows linearly with the number of response variables, rather than exponentially, enabling efficient full-probabilistic analysis for high-dimensional nonlinear engineering systems using a limited number of representative simulations. The paper further demonstrates the versatility of the decoupled framework through three representative applications in engineering risk assessment. First, a full-probabilistic seismic fragility analysis is developed using a decoupled M-PDEM-based cloud approach, which directly yields the joint and conditional PDFs of intensity measures and engineering demand parameters without assuming lognormality or relying on empirical regression. Second, the framework is integrated with a virtually conditionalized reliability evaluation strategy to establish a non-iterative dynamic reliability-based design optimization paradigm, effectively eliminating the costly double-loop reanalysis commonly encountered in traditional reliability optimization. Third, the method is extended to probabilistic inverse problems, where the conditional PDFs of unobserved system states are reconstructed from partial observations, providing a complete probabilistic characterization of hidden responses under uncertainty. Numerical examples involving nonlinear structural systems under nonstationary stochastic excitation demonstrate that the proposed method achieves accuracy comparable to Monte Carlo simulations with the number of system evaluations in fewer orders of magnitude. The results highlight the strong potential of the decoupled M-PDEM as an advanced computational tool for uncertainty propagation, fragility assessment, reliability optimization, and risk-informed decision-making in engineering applications.

Speaker



Meng-Ze Lyu

Research Fellow | Leibniz University Hannover

ID 274: Subset Simulation with a Modified Component-wise Intrepid MCMC Sampler for Structural Reliability Estimation

4:20 PM – 4:40 PM

Author(s): Adwait Sharma, Johns Hopkins University; Promit Chakroborty, Vanderbilt University; Michael Shields, Johns Hopkins University

Discontinuities in performance functions and multiple or disconnected failure regions pose significant challenges in computational structural reliability estimation. When performance functions exhibit these geometric characteristics, even well-established variance reduction techniques may fail to account for all important failure regions, leading to substantial underestimation of failure probabilities. Subset simulation is a widely used approach for failure probability estimation. In the context of Subset Simulation, these issues arise as challenges in sampling from multimodal conditional probability density functions (pdfs), where the locations of the modes and their relative contributions are a priori unknown. Consequently, the underlying Markov Chain Monte Carlo (MCMC) sampler must identify and correctly sample from all important modes of the target conditional pdf. The sampler must therefore be designed to effectively explore the standard normal space. Improving this aspect of MCMC samplers in the context of Subset Simulation has received limited attention in the current literature.

In this work, we employ the Intrepid MCMC sampler, which has recently been shown to outperform the random walk Metropolis-Hastings sampler in generating samples from multimodal pdfs. We present a modified component-wise Intrepid MCMC specifically designed to enhance exploration in the standard normal space. The Intrepid Markov transition pdf is obtained as the composition of two transition pdfs: (a) one that explores the standard normal space in search of previously undetected failure regions, and (b) another that generates samples from the currently identified failure region. This allows the MCMC sampler to generate improved samples from multimodal conditional standard normal pdfs compared to samplers traditionally used within Subset Simulation. The improved ability of the Intrepid MCMC sampler to explore the standard normal space is shown to be crucial for accurate estimation of failure probability when the underlying performance function has discontinuities or multiple and/or disconnected failure regions. We demonstrate the effectiveness of the proposed sampler on structural reliability problems where these challenges arise, including forced vibration of a two-degree-of-freedom mass-spring-dashpot system, a structure exhibiting stable-symmetric buckling, and a von Mises truss exhibiting snap-through buckling. We demonstrate the effectiveness of the Intrepid sampler in dealing with such performance functions and compare the results with three MCMC samplers which have been used within Subset Simulation: (a) the Modified Metropolis sampler, (b) the Conditional U-space sampler, and (c) the Replica-Exchange MCMC sampler.

Speaker



Adwait Sharma

Dr. | Johns Hopkins University

ID 299: A decoupled density-evolution framework for dynamic reliability of engineering structures with multiple failure criteria

4:40 PM – 5:00 PM

Author(s): Yongfeng Zhou, Tongji University; Jie Li, Tongji University

Dynamic reliability is a crucial indicator for assessing the safety of engineering structures, particularly under catastrophic dynamic loads such as earthquakes, strong winds and explosions. The commonly used Monte Carlo simulation method struggles to obtain rational and accurate dynamic reliability analysis results due to issues like low computational efficiency and random convergence. The establishment of probability density evolution method (PDEM) clarified the fundamental approach of researching stochastic systems through changes in physical states. The generalized probability density evolution equation (GDEE) is proved to be the governing equation of describing the basic laws of randomness propagation. Combining GDEE with the absorbing boundary condition method (ABCM), the dynamic reliability for engineering structures with the single failure criterion can be determined. In this work, the application of ABCM for dynamic reliability analysis has been extended to multiple failure criteria based on the decoupled multi-probability density evolution method (M-PDEM). The decoupled M-PDEM is newly developed to capture the joint probability density function of multiple response processes of a system. The solution of the original multi-dimensional GDEE is simplified to solving multiple one-dimensional GDEE. Therefore, by applying ABCM to each one-dimensional equation separately, dynamic reliability under multiple failure criteria can be got. The proposed method has been verified through several examples, including the single degree of freedom system (SDOF) and the Euler-Bernoulli beam under random excitations, and there is great agreement between the numerical results and the precise solutions of dynamic reliability. Besides, a nonlinear reinforced concrete frame with random structural parameters under seismic load has been considered, and the corresponding dynamic reliability has been obtained.

Speaker



Yongfeng Zhou

PhD Student | Tongji University

ID 414: Quantifying Thermal Failure Risk for NASA's Dragonfly Titan Entry Under Chemical–Radiative Uncertainty

5:00 PM – 5:20 PM

Author(s): Audrey Gaymann, University of Colorado - Boulder; Alireza Doostan, University of Colorado - Boulder; Michael Sands, University of Colorado - Boulder; Sung Min Jo, University of Central Florida

NASA's Dragonfly mission to Titan presents a uniquely challenging atmospheric entry environment characterized by extreme aerothermal loads and significant physical and chemical uncertainties. During hypersonic entry into Titan's dense, nitrogen–methane atmosphere, the thermal protection system is subjected to intense convective and radiative heating, with system response strongly influenced by poorly constrained parameters such as gas-phase chemical reaction rates, freestream methane concentration, and radiative excitation processes. These uncertainties directly affect the prediction of material response and structural integrity, motivating the need for a rigorous reliability framework capable of quantifying the probability of failure under high-dimensional aleatory uncertainty.

In this work, we assess the reliability of the Dragonfly entry system by evaluating the probability that the bondline temperature—an essential indicator of thermal protection system performance—exceeds a prescribed failure threshold. High-fidelity computational fluid dynamics (CFD) simulations coupled with radiation modeling and a solid heat conduction solver are employed to compute the bondline temperature along the vehicle forebody. An ensemble of simulations is generated by randomly sampling uncertain gas-phase kinetic parameters, material thermal conductivities, and radiative excitation rates, enabling a detailed characterization of how physical and chemical uncertainties propagate to system response. To reduce the dimensionality of the uncertainty space and identify dominant contributors to failure, a global sensitivity analysis is performed, providing a principled screening of influential parameters.

Given the prohibitive computational cost of repeated high-fidelity simulations, a multi-fidelity reliability framework is introduced. A global surrogate model is first constructed to approximate the response over the full parameter space. This surrogate is then exploited to identify regions near the bondline temperature threshold that are most critical to reliability estimation. Within these high-sensitivity regions, Christoffel adaptive sampling is employed to concentrate samples where accurate resolution of the limit-state surface is essential. Selected samples are subsequently evaluated using the high-fidelity solver, yielding refined local surrogates and enabling accurate estimation of failure probability at a fraction of the cost of brute-force Monte Carlo sampling. Results demonstrate that the combined use of multi-fidelity modeling and Christoffel adaptive sampling substantially reduces computational expense while preserving predictive accuracy in the vicinity of the failure boundary.

Speaker



Audrey Gaymann

Dr. | University of Colorado at Boulder

ID 505: High-Dimensional Emulation of Hurricane-Driven Coastal Flood Evolution using Hybrid Neural Networks

5:20 PM – 5:40 PM

Author(s): Liuyun Xu, University of Texas at Arlington; Sejin Kim, Chungbuk National University; Seymour M.J. Spence, University of Michigan

To address the computational burden associated with large-scale high-fidelity hydrodynamic simulations in the context of uncertainty propagation, machine learning (ML)-enabled emulation has emerged as a promising alternative for rapidly predicting flood evolution in coastal communities. Nevertheless, this task often becomes challenging due to the high dimensionality of large geographic domains and the complex spatiotemporal nonlinear dynamics over long durations (e.g., several hours). Therefore, this paper develops a deep learning-based emulation framework for efficiently predicting high-dimensional flood evolution across both spatial and temporal scales. Within this framework, a nonlinear dimensionality technique (e.g., convolutional autoencoders) is first employed to transform the community-scale flood water levels into a lower-dimensional latent space while preserving essential spatial features. Subsequently, a sequence-to-sequence mapping from hurricane trajectories to latent representations is established by leveraging convolutional recurrent neural networks. Once trained, the emulator can rapidly predict low-dimensional representations under new hurricane scenarios, which are then decoded to the full flood evolution. Through a case study on Marco Island, Florida, the proposed framework has been demonstrated to be capable of accurately emulating high-dimensional flood evolution over extended time horizons under extreme hurricanes, while achieving significant computational speedups relative to high-fidelity simulations. Moreover, the results indicate that the proposed scheme enables superior training efficiency compared with existing ML-driven emulation frameworks as dimensionality increases.

Speaker



Liuyun Xu

Assistant Professor | The University of Texas at Arlington

ID 603: Generative AI-enhanced Probabilistic Multi-Fidelity Surrogate Modeling Via Transfer Learning

5:40 PM – 6:00 PM

Author(s): Jice Zeng, Pacific Northwest National Laboratory; David Barajas-Solano, Pacific Northwest National Laboratory; Hui Chen, Wuhan Institute of Technology

The performance of machine learning surrogates is critically dependent on data quality and quantity. This presents a major challenge, as high-fidelity (HF) data is often scarce and computationally expensive to acquire, while low-fidelity (LF) data is abundant but less accurate. To address this data-scarcity problem, we develop a probabilistic multi-fidelity surrogate framework based on generative transfer learning. We employ a normalizing flow (NF) generative model as the backbone, which is trained in two phases: (i) the NF is first pretrained on a large LF dataset to learn a probabilistic forward model; (ii) the pretrained model is then fine-tuned on a small HF dataset, allowing it to correct for LF–HF discrepancies via knowledge transfer. To relax the dimension-preserving constraint of standard bijective NFs, we integrate surjective (dimension-reducing) layers with standard coupling blocks. This architecture enables learned dimension reduction while preserving the ability to train with exact likelihoods. The resulting surrogate provides fast probabilistic predictions with quantified uncertainty and significantly outperforms LF-only baselines while using fewer HF evaluations. We validate the approach on a reinforced concrete slab benchmark, combining many coarse-mesh (LF) simulations with a limited set of fine-mesh (HF) simulations. The proposed model achieves probabilistic predictions with HF accuracy, demonstrating a practical path toward data-efficient, generative AI-driven surrogates for complex engineering systems.

Speaker



Jice Zeng

PostDoc RA | Pacific Northwest National Laboratory

MS 068: Surrogate Modeling for Uncertainty Quantification, Optimization, and Statistical Inference in Engineering Applications

4:00 PM – 6:00 PM | Location: ECON 119

Chair(s): Alexandros Taflanidis; Bruno Sudret; Abdollah Shafieezadeh; Gaofeng Jia; Min Li

Moderators



Alexandros Taflanidis

Professor | University of Notre Dame

ID 853: Robust Design Optimization under Dependent Random Variables by a Generalized Polynomial Dimensional Decomposition

4:00 PM – 4:20 PM

Author(s): Muhammad Talukdar, The University of Iowa; Sharif Rahman, The University of Iowa

New computational methods are proposed for robust design optimization (RDO) of complex engineering systems subject to input random variables characterized by arbitrary and dependent probability distributions. The proposed framework is built upon a novel generalized polynomial dimensional decomposition (GPDD) for accurately evaluating the second-moment statistics of general output functions with dependent input [1], an innovative integration of GPDD with score functions for efficiently computing second-moment sensitivities with respect to design variables, and a conventional gradient-based optimization algorithm. These components collectively establish direct GPDD, single-step GPDD, and multi-point, single-step GPDD design strategies to deal with a broad range of design optimization problems. In addition, new analytical formulae are derived for design sensitivity analysis, allowing statistical moment evaluation and sensitivity computation to be performed simultaneously within a unified framework. Numerical studies demonstrate that the proposed methods yield accurate and computationally efficient optimal solutions for a variety of mathematical and benchmark RDO problems. Moreover, the successful application to the stochastic shape optimization of a practical engineering system further illustrates the robustness and effectiveness of the multi-point, single-step GPDD method in solving industrial-scale problems.

[1] Talukdar, M. and Rahman, S., "Toward Uncertainty Quantification with Arbitrarily Dependent Probability Distributions of Random Input," submitted to Computer Methods in Applied Mechanics and Engineering, 2025.

Speaker



Rashel Talukdar

The University of Iowa

ID 878: A study of reduced stochasticity Bayesian neural networks with application to surrogate modeling of power flow solvers

4:20 PM – 4:40 PM

Author(s): Nicholas Casaprima, University of Southern California; Somayajulu L. N. Dhulipala, Idaho National Laboratory; Audrey Olivier, University of Southern California; Bjorn Vaagensmith, Idaho National Laboratory

Neural network (NN) architectures – e.g. convolutional, graph or transformer – are a powerful tool to surrogate complex physics-based simulators, with applications in mechanics, weather modeling, power grid to cite only a few. Their efficiency in making predictions enables real-time decision-making, or integration within optimization schemes that require many calls to the simulator. Embedding these NN architectures with efficient uncertainty quantification (UQ) – in particular epistemic uncertainties that stem from lack of data – also allows to assess confidence in predictions for out-of-distribution predictions. UQ in NNs is key to enabling trust for deployment in high-stakes decision-making, e.g. power grid remedial actions, and provides a means to optimize data collection procedures via uncertainty-based sampling. However, the high-dimensionality of a typical NN parameter space presents a challenge in applying Bayesian inference in this context, both in terms of prior design and posterior computation. In this talk we investigate reduced stochasticity NNs, designing appropriate priors and leveraging anchored ensembling for posterior estimation. We study two means of reducing the size of the parameter vector in fully-connected NNs: focusing stochasticity to one or few layers, or leveraging low-rank weight updates (a popular means to fine-tune transformers in the deterministic setting). We show results on a power flow surrogate modeling application, using data from low fidelity simulators for pre-training, and assessing capabilities of reduced stochasticity frameworks to appropriately embed UQ at the fine-tuning stage when training data is more expensive to collect.

Speaker



Nicholas Casaprima

PhD Candidate | University of Southern California

ID 943: Differentiable Predictive Control for Rapid Flood Mitigation

4:40 PM – 5:00 PM

Author(s): Graham Hults, Johns Hopkins University; Susu Xu, Johns Hopkins University; Ján Drgoňa, Johns Hopkins University

This work introduces an end-to-end, Differentiable Predictive Control (DPC) neural network policy architecture for flood barrier deployment around a critical facility to minimize inundation while enforcing hard physical and operational constraints. The primary contributions of this work are: (1) a DPC-based framework for real-time flood barrier deployment given a rainfall forecast, (2) a direct benchmark against Model Predictive Control formulated as a Mixed-Integer Quadratic Program and solved online using a commercial solver, and (3) a physics-aware evaluation across diffusion-based and linearized shallow water flood dynamics. In flash flood scenarios, decision-support tools must operate within narrow time windows; however, traditional optimization-based approaches often incur substantial computational costs and slow online performance due to large, discrete decision spaces typically solved via branch-and-bound or cutting-plane methods. Compounding this challenge, state-of-the-art precipitation forecasting is typically reliable only at short lead times (i.e., a 6-hour window) which limits the reliability of parameterizing decision-support tools with long-horizon meteorological forecasts. DPC addresses these limitations by shifting standard computational complexities offline, where a neural network policy is trained end-to-end via automatic differentiation through a constrained optimizer across diverse flood forecast scenarios. Once trained and deployed, DPC enables rapid closed-loop decision-support and control at inference time while respecting physical and resource constraints. This application compares the performance of a Model Predictive Control problem formulated as a Mixed Integer Quadratic Program using a commercial solver online at each control step against the DPC-MIQP framework. Both approaches prescribe decisions across the same set of randomized rainfall events produced by Gaussian Random Fields and initial depth locations governed by finite-volume, diffusion-based, and linearized flood wave dynamics (simplified Shallow Water Equations). The physics governing flood dynamics are simplified by diffusive processes to ensure comparable solutions otherwise not guaranteed by a complex MINLP formulation. Comparing model performance across 30 scenarios, DPC outperforms MPC on all fronts: on average, DPC reduced flood depth by 0.203 m while MPC only reduced flood depth by 0.082 meters, DPC was 3024x faster during online performance, and demonstrated greater barrier efficiency metrics demonstrating 4.4x smarter deployment versus the MPC baseline.

Speaker



Graham Hults

Graduate Research Assistant | Johns Hopkins University

ID 1007: An Efficient Arbitrary-Order Sensitivity Analysis Method Using Hybrid Hypercomplex Automatic Differentiation for Finite Element Models

5:00 PM – 5:20 PM

Author(s): Mauricio Aristizabal, St. Mary's University; Manuel Garcia, Angelo State University

Sensitivity analysis plays a pivotal role in advancing computational mechanics, serving as a cornerstone for reduced order modeling, machine learning integration, uncertainty quantification, and gradient-based optimization. While the utilization of high-order derivatives can significantly reduce the computational time required for these workflows, accurately computing these sensitivities remains a challenge due to the high costs associated with compute time and memory usage.

Hypercomplex Automatic Differentiation (HYPAD), particularly with the use of Order Truncated Imaginary (OTI) numbers, has recently been shown as a highly effective approach for computing the sensitivities of non-linear finite element models, offering both performance benefits and high numerical accuracy. However, a significant barrier to the widespread adoption of HYPAD is the requirement for full access to the computational source code. In many practical scenarios, critical components, such as complex material models or elemental equations, are only available as "black boxes;" rendering standard HYPAD implementation impossible.

This work presents an efficient hybrid strategy to compute arbitrary-order derivatives of finite element models, specifically designed to handle simulation frameworks where internal solver operations are partially inaccessible. The proposed approach employs a post-processing strategy that begins by solving the original problem using conventional software, such as Ansys or Abaqus. During the sensitivity evaluation stage, the method evaluates the problem residual at the element domain to obtain imaginary coefficients that contain derivative information. For components where the source code is inaccessible and cannot accept hypercomplex inputs, the function is locally sampled. These samples are then used to approximate derivatives via a generalized finite difference strategy, which is mathematically integrated with the hypercomplex algebra workflow.

We evaluate the performance of this hybrid approach by benchmarking it against a pure HYPAD implementation where full source code is available. Finally, the versatility of the method is demonstrated through applications in non-linear heat transfer and solid mechanics. The novel approach provides the flexibility to work with modules whose source code is not available, enabling accurate sensitivity analysis without requiring intrusive code modifications.

Speaker



Mauricio Aristizabal

Assistant Professor of Mechanical Engineering | St. Mary's University

ID 968: Optimal design of experiments: An approach based on differential geometry-inspired scoring measures:

5:20 PM – 5:40 PM

Author(s): David Gillcrist, University of Massachusetts Dartmouth; Arghavan Louhghalam, UMass Lowell; Yanlai Chen, University of Massachusetts Dartmouth; Mazdak Tootkaboni, University of Massachusetts Dartmouth

Optimally designed experiments lead to improved parameter estimation, especially when available experiments yield minimal data due to limited experimental budget and practical constraints. This work presents a novel framework that allows for the identification of optimal experimental designs from a finite set of candidate arrangements toward precise parameter estimation. The proposed framework leverages the computational economy of multi-fidelity surrogates, relating unknown parameters to a measurable quantity of interest tied to a design primitive (e.g., detector location), enabling efficient exploration of a candidate arrangement's "estimation potential." We define differential geometry-inspired global measures of this estimation potential, which are complemented by the introduction of novel, measure theoretic-derived preconditioning methods for the minimization problem. Numerical examples are provided, where we present strong correlations between the introduced measures and the estimation success rate (SR) for arrangements. Furthermore, we demonstrate the effect of our proposed preconditioning strategy on the SR outcomes for each candidate arrangement.

Speaker



Arghavan Louhghalam

UMass Lowell

MS 074: Innovations in CFD and FSI: Rigorous Methods with Practical Applications

4:00 PM – 6:00 PM | Location: CHEM 140

Chair(s): Yuri Bazilevs; Ming-Chen Hsu; Artem Korobenko; Georgios Moutsanidis; Jinhui Yan

Moderators



Jinhui Yan

Associate Professor | University of Illinois Urbana Champaign

ID 718: A Particle-Based Fluid–Structure Interaction Framework for Brittle Fracture under Extreme Hydrodynamic Loading

4:00 PM – 4:20 PM

Author(s): George Moutsanidis, Rutgers University; Mohammad Naqib Rahimi, Synopsys Inc.

Extreme hydrodynamic events can induce severe deformation, damage, and fracture in coastal and offshore structures, requiring numerical frameworks capable of resolving free-surface flows, large deformations, and fracture in a unified setting. This work presents a particle-based fluid–structure interaction (FSI) framework that serves as a prototype and proof of concept for modeling brittle fracture and fragmentation of structures subjected to extreme hydrodynamic loading.

The approach employs smoothed particle hydrodynamics (SPH) for both fluid and solid domains, leveraging its meshfree formulation to naturally handle free surfaces, large deformations, and material separation. Structural fracture is modeled using a phase-field formulation of brittle fracture, enabling crack initiation and propagation without explicit crack tracking. A two-way coupling strategy is introduced to exchange pressure and kinematic information between the fluid and solid solvers while allowing different spatial resolutions in each domain.

The framework is verified and validated against benchmark problems and experimental results, and is applied to representative FSI scenarios involving fracture and structural disintegration. While the current implementation is not intended to resolve full-scale coastal structures, it should be viewed as a first step toward more comprehensive, high-fidelity FSI simulations. Ongoing work focuses on incorporating advanced concrete constitutive modeling and GPU-accelerated, open-source implementations to extend the framework toward large-scale extreme event applications.

Speaker



George Moutsanidis

Assistant Professor | Rutgers University

ID 787: Dynamic Fluid-Structure Interaction at the Atomic Limit

4:20 PM – 4:40 PM

Author(s): Narayana Aluru, University of Texas at Austin

In this talk, we will investigate how atomic-scale vibrational coupling at a solid-fluid interface affects wettability and other fluid properties such as friction and slip. First, by performing all atom molecular dynamics (MD) simulations, we investigate how the wetting of water droplets on a substrate changes with the frequency of excitation of the substrate. We show that the wetting properties can be significantly altered by the frequency of excitation. We discuss the mechanisms governing physicochemical behavior of fluids at solid-fluid interfaces in the presence of vibrational coupling. Next, we investigate water and ion transport through confined spaces. We discuss the effect of wall excitations on friction coefficient and water and ion transport. We show that transport rates can be quite different from rigid counterparts. Finally, we investigate water transport through vibrating nanoporous membranes and show that non-equilibrium fluctuations can have a significant effect on water transport. We discuss some potential applications that could benefit from these studies.

Speaker



Narayana Aluru

Professor | University of Texas at Austin

ID 944: A stabilized finite element formulation for fluid-structure interaction with non-conforming interfaces

4:40 PM – 5:00 PM

Author(s): Yusuf Salaudeen, Department of Civil, Construction, and Environmental Engineering; North Carolina State University, Raleigh, NC; Ghadir Haikal, Department of Civil, Construction, and Environmental Engineering; North Carolina State University, Raleigh, NC

Fluid–structure interaction (FSI) arises in many engineering and scientific applications involving a moving fluid–solid interface, such as marine and offshore structures, biomedical flows, aerospace components, and porous media. Accurate FSI simulation remains challenging due to strong fluid–structure coupling and the need to enforce kinematic and dynamic interface compatibility. These difficulties are amplified when different discretizations in the fluid and solid domains lead to a non-conforming interface, as continuity of displacement and consistent traction transfer are no longer automatically guaranteed. Nevertheless, non-conforming interfaces are attractive because they facilitate the coupling of independently generated fluid and structural discretizations with finer meshes typically needed in the fluid domain.

Existing FSI methodologies can be broadly classified according to their discretization frameworks, interface-tracking strategies, and coupling schemes, including monolithic and partitioned approaches. Body-fitted Arbitrary Lagrangian-Eulerian (ALE) formulations, least-squares and optimization-based coupling strategies, and Lagrangian methods such as Particle Finite Element Method (PFEM) have all been successfully applied to FSI problems. However, these methods often require complex mesh motion or regeneration, intricate interface tracking, dual interpolations of traction fields, or problem-specific stabilization techniques, which can limit robustness and scalability, particularly for large deformations or evolving interfaces.

In this study, we propose an enriched Discontinuous Galerkin framework for the coupling of non-conforming meshes in FSI problems. The proposed approach guarantees kinematic compatibility and enforces interface traction continuity in a variationally consistent manner without the need for mesh conformity, remeshing, or empirical interpolation, while enabling accurate, stable coupling and preserving local conservation properties.

Keywords: Fluid Structure Interaction, Non-conforming mesh, Enriched Discontinuous Galerkin formulations, Interface coupling

Speaker



Yusuf Salaudeen

North Carolina State University

ID 984: A Volterra Theory-Guided Network for Modeling Nonlinear Post-flutter Behaviors of Solar Trackers

5:00 PM – 5:20 PM

Author(s): Seyed Pejman Fatehi, Colorado State University; Yanlin Guo, Colorado State University; Teng Wu, University at Buffalo

Solar trackers are prone to wind-induced torsional flutter instability. While the linear unsteady analysis framework has been well developed to accurately predict the critical flutter wind speed (onset of instability), it is generally incapable of modeling the post-flutter limit cycle oscillations (LCOs) associated with nonlinear bluff-body aeroelasticity. Although significant efforts have been made to advance nonlinear reduced-order models for the simulation of post-flutter behaviors of aerodynamic-sensitive structures, the efficient and accurate identification of model parameters is quite challenging. Recent development of deep neural networks (DNNs) shows great promise for the simulation of nonlinear unsteady aeroelasticity of solar trackers, having the network parameters auto-learned without much human intervention. However, a large amount of high-fidelity training data [e.g., obtained with computational fluid dynamics (CFD)] is needed.

To improve the data efficiency of DNN in learning the post-flutter behaviors of solar trackers, this study leverages Volterra theory to guide the network configuration design. The Volterra series, consisting of linear and higher-order convolutions, can be utilized to represent the complex mapping rules (static linear/nonlinear relationships) and time lags (fluid memory effects) between the aeroelastic inputs and outputs of solar trackers. By implementing third-order discrete-time Volterra operators as differentiable layers in the DNN, the network consists of parallel convolutional branches with trainable parameters (or compact low-rank factors) and are learned directly from structural motion-aeroelastic force dataset. The Volterra theory-guided network (VTGN) addresses the high data requirement of standard DNNs by imposing a structural bias derived from Volterra theory, which constrains the network's hypothesis space to physically consistent convolutional operators that explicitly encode time-lagged (memory) effects and low-order polynomial nonlinearities. By utilizing trilinear tensor decompositions to represent third-order kernels, the network transforms a high-dimensional weight-search into a parsimonious optimization of basis coefficients to overcome the curse of dimensionality. This gray-box regularization allows the model to converge using sparse broadband CFD data whereas a generic black-box DNN would remain under-determined or prone to over-fitting. The obtained VTGN receives torsional tracker displacement θ , reduced wind velocity U_r , and initial angle between wind and tracker α_0 as inputs to predict the aerodynamic moment coefficient C_m . This output is coupled with a solar tracker structural dynamics model to solve the fluid-structure interaction for modeling the amplitudes and frequencies of post-flutter LCOs.

Validation against CFD measurements demonstrates that the VTGN captures angle-dependent stability boundaries and post-flutter limit-cycle amplitudes with significantly less data compared to a standard DNN. In addition, the VTGN presents improved explanation and transparency by allowing the direct extraction of physically interpretable kernels from trained weights. Specifically, the extracted first-order kernel provides the system aerodynamic impulse response function which reveals the linearized unsteady behavior of the fluid. Simultaneously, the learned truncation lengths provide a direct measurement of the aerodynamic memory duration as the Laguerre parameter is optimized during training to control the exponential declining rate of the response.

Speaker



Seyed Pejman Fatehi

Ph.D. Student and Graduate Research Assistant | Colorado State University

ID 1037: Determination of Wave Transmission Coefficients for a Moored Floating Breakwater

5:20 PM – 5:40 PM

Author(s): Jacob Milliken, U.S. Army Engineer Research and Development Center (ERDC); Christopher Denney, U.S. Army Engineer Research and Development Center (ERDC)

Located in the north of Juneau is Auke Bay, a deep water bay where much of the ship traffic comes in for shipments. The sea conditions in this bay are fairly extreme, with significant wave heights and peak periods of 6ft and 6s respectively according to the Joint North Sea Wave Project (JONSWAP) wave spectra. The current ladder-type floating breakwaters used in Auke Bay are significantly past their intended lifespan and are due for a replacement, and the Alaska District is interested in further investigation of the solid floating breakwater geometry for future replacement. Advanced numerical modeling will inform the design and replacement of aging harbor structures under complex tidal and wave conditions. A computational fluid dynamics (CFD) study was performed to validate against a previous naval study and also to examine the effects of various floating breakwater parameters on the effectiveness of attenuating incoming waves that pose a threat to critical harbor infrastructure. Many experimental physical models of floating breakwaters in current literature investigate the effect of various breakwater geometries which restricts the available data that can be compared to when considering a simple rectangular box geometry configuration. There are other discrepancies such as mooring line tension, mounting locations, and regular waves as opposed to irregular waves which can obfuscate conclusions for comparisons with different configurations. A prototype scale is used for the numerical modeling effort to validate the naval study, and the effects of varying wave spectra, mooring line configurations, and geometric parameters are investigated for their effect on improving the wave attenuation capabilities of floating breakwaters.

Speaker



Jacob Milliken

ERDC

MS 078: Wind, surge-wave, flooding and their impacts on infrastructure systems and coastal land

4:00 PM – 6:00 PM | Location: UMC 247

Chair(s): Chao Sun; Celalettin Ozdemir

Moderators



Chao Sun

Associate Professor | Louisiana State University

ID 778: High-Resolution Numerical Modeling of Near-Field Free-Surface and Ground Response to Impulsive Marine Events

4:00 PM – 4:20 PM

Author(s): Ryan Denney, US Army Corps of Engineers; Jacob Milliken, US Army Corps of Engineers

Sudden, high-energy release events in the ocean can generate intense, short-duration disturbances that strongly influence the resulting surface wave field. The characteristics of these waves are established during the early stages of the event, where rapid pressure changes, strong velocity gradients, and interactions between the water column, free surface, and underlying ground dominate the response.

This work presents numerical simulations of impulsive energy release underwater, with emphasis on the near-field response immediately following the event. A high-resolution computational model is used to resolve the initial shock dynamics, the development of the free-surface disturbance, and the response of the surrounding ground. The simulations capture the coupled evolution of pressure, velocity, and surface elevation in the vicinity of the source region over short time scales.

Results focus on describing the structure and evolution of the near-field flow, surface response, and ground motion under varying conditions, including differences in water depth and local geometry. The interaction between the fluid and the underlying ground is examined in terms of spatial and temporal patterns observed in the solution.

The study provides a detailed description of near-field behavior associated with impulsively generated marine events and contributes to a clearer understanding of the early-time processes that shape the initial surface wave field. The results support continued investigation of extreme marine disturbances and their broader implications for wave propagation and coastal interaction.

Speaker



Christopher Denney

US Army Corps of Engineers

ID 837: The Effects of Debris Impact and Damming on Prestressed Girders Due to Flooding

4:20 PM – 4:40 PM

Author(s): Nida Virabalin, Texas A&M University

Bridges are a travel gateway that connects communities together. When a disaster occurs, first responders and the community rely on these bridges to cross the water and reach safety. When the bridges fail due to the flood, it halts first aid help from entering the community and prevents people from leaving the disaster-affected area safely. The cost of bridge repairs from flooding events is also expensive. From the flooding event in Kerr County, TX, in 2025, the city paid \$1.4 million to repair the bridges impacted. With the increase in flood risk in the United States, states have started improving lateral restraints to protect bridges against hydrodynamic forces. However, impact loads from debris and damming forces, along with their impact on prestressed bridge girders, have yet to be studied in detail.

This research will identify the impact forces of common debris, such as trees, vehicles, and shipping containers, on girders using ABAQUS/CAE explicit and apply these forces experimentally to standard TXDOT prestressed bridge girders. Work has been done in the ABAQUS simulation to ensure the output of the hydrodynamic and debris impact on a thin, rigid wall is accurate before replacing the thin wall with prestressed girders. The Coupled Eulerian-Lagrangian (CEL) method creates an Eulerian water boundary that allows the Lagrangian debris to impact the wall. ABAQUS explicit uses kinematic contact to calculate the forces of interest with the dynamic equilibrium equation. The stresses, reaction forces, and deflection are extracted from ABAQUS, and the graphs and forces are created using MATLAB. Currently, the model contains the prestressed girders being impacted by both cylindrical and rectangular debris of different materials to observe the impact effects of shape, size, and material. Different materials and sizes will be used to encapsulate the possible debris that could impact girders during a flooding event. Another model is made as well to observe the impact of damming by causing the debris to stay in contact with the girders after impact. After identifying the failure points caused by the debris from both impact and damming, remediation effects will be designed to help strengthen current bridges. The results of this research will inform bridge design codes to help engineers design bridges that can withstand hydrodynamic and debris forces during flooding events, in hopes of protecting the people and costing the government less money during disasters.

Speaker



Nida Virabalin

Ms | Texas A&M University

ID 986: Measuring Coastal Conditions during the 2024 Atlantic Hurricane Season Using an Advanced Wind-Surge-Wave Experimental Platform (Project Sentinel)

4:40 PM – 5:00 PM

Author(s): Ehsan Ahmadi Afzadi, Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA; Zanti Rains, Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA; Brian Phillips, Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA; Justin Davis, Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA; Forrest Master, College of Engineering, Oregon State University, Corvallis, OR, USA; Chris Ferraro, Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA; Pedro Fernández-Cabán, College of Engineering, Florida A&M University–Florida State University, Tallahassee, FL, USA; Britt Raubenheimer, Woods Hole Oceanographic Institution, Massachusetts, USA; Elise Morrison, Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA; Maitane Olabarrieta, Engineering School of Sustainable Infrastructure and Environment, University of Florida, Gainesville, FL, USA

Tropical cyclones produce a coupled set of wind, surge, wave, and flood-related processes that interact nonlinearly and heterogeneously in the coastal and near-shore environment. While computational fluid dynamics and structural analysis are continually improving, the prediction of structural response and failure during multi-hazard events is limited by the lack of high-quality near-shore field data, such as detailed wind, wave, and surge measurements during hurricane landfalls, which are often difficult to obtain due to the extreme conditions. Building on the successful Florida Coastal Monitoring Program (FCMP), the Sentinel towers enhance data collection by being installed along the shoreline, thereby both withstanding and recording wind and water hazards more effectively in the land–sea boundary environment. Sentinel towers are deployed in coordination with other hurricane monitoring equipment to fill critical hazard data gaps along the coast.

The Mark I design of Sentinel consists of four six-meter-long steel piles, an aluminum pile cap, and a 10-meter-tall carbon fiber mast, enabling standard 10-meter wind measurements. It is designed for rapid or long-term deployment and engineered to withstand extreme wind speeds (up to 200 mph), elevated water levels, and wave heights up to 16 ft. Mark I's instrumentation includes anemometers measuring 3D winds, atmospheric sensors for pressure, temperature, and humidity, a tiltmeter to measure mast motion, and water sensors to capture depth, temperature, and salinity. Data is saved locally and relayed in real-time to servers at the University of Florida for distribution and visualization by first responders, real-time hurricane modelers, and groups that broadly disseminate information to the public. The system is also designed as a flexible platform capable of carrying observation payloads from other researchers.

In 2024, the first full-scale deployments of Sentinel Mark I took place in Florida, with two towers deployed in advance of Hurricane Helene at Cedar Key Public Beach and Mashles Sands Beach. Shortly thereafter, the same towers were deployed in Hurricane Milton at Holmes Beach and Venice Beach. During both hurricanes, the towers remained operational, providing continuous real-time data. The dataset generated offers new insights into the forces at play in the nearshore environment during hurricanes, contributing significantly to our understanding of coastal dynamics.

The insights gained from the initial deployment informed the design of the new Mark II version of the Sentinel, which includes enhanced instrumentation redundancy, high-resolution cameras, and tower-mounted LiDAR. The cameras and LiDAR provide more complete condition monitoring, including beach profiles and water conditions before, during, and after the event. A combination of Mark I and Mark II Sentinels will be ready for the 2026 Atlantic Hurricane Season. The network of Sentinel towers provides crucial field measurements that serve as a ground truth for advancing coastal hazard resilience.

Speaker



Ehsan Ahmadi Afzadi

Graduate Student | University of Florida

ID 915: Numerical Investigation of Reduction in Wave and Current Loads on Coastline Structures behind Nature-Based Defense

5:00 PM – 5:20 PM

Author(s): Navid Tahvildari, Florida International University; Abdollah Ojaghi, Florida International University; Pedro Lomonaco, Oregon State University

Coastal Infrastructure is under increasing threat from ocean-based natural hazards. Storm surge and waves and the resulting overland currents can apply destructive loads on coastline buildings, and this threat is increasing due to rise in sea level and projected increase in hurricane intensity. Nature-based solutions, including coastal and estuarine vegetation, are increasingly promoted as measures for reducing hydrodynamic loads, yet quantitative understanding of how vegetation modifies these loads on coastline buildings remains limited. Specifically, how the presence of currents affects wave loads still needs to be investigated. In this study, we use computational fluid dynamics to study wave- and current-induced forces acting on idealized coastline structures, in isolation and in combination. A model based on OpenFOAM is developed to simulate wave propagation, current flow, wave-current interactions through vegetated canopies and to calculate the resulting loads on idealized structures located in the lee of the vegetation. The vegetation is represented using a parameterized drag formulation that accounts for stem density, thickness, and submergence ratio. The model will be validated with large-scale experiments performed using laboratory measurements conducted at Oregon State University, focusing on scenarios with periodic wave only, uniform currents only, and simultaneous presence of waves and currents. Datasets including measurements of free-surface elevation and velocity fields upstream and downstream of vegetated fields, and loads measurements will be used for model validation. While validation for combined wave and current scenarios will be conducted for co-propagating waves and currents, the effect of counter-propagating currents will be investigated numerically. Finally, a parametric study will be conducted to quantify the sensitivity of predicted structural loads to wave height and period, current velocity and direction, and vegetation characteristics. Results elucidate the relative contributions of waves, currents, and their interaction to structural loading in vegetated coastlines and to identify regimes in which vegetation provides considerable protection. The findings aim to support the development of improved predictive tools for evaluating the protective capacity of nature-based defense for coastal resilience.

Speaker



Navid Tahvildari

Associate Professor | Florida International University

ID 646: Seismic response of a resilient and sustainable system via real-time hybrid simulation

5:20 PM – 5:40 PM

Author(s): Kostas Kalfas, Texas State University; Liang Cao, University of Mississippi; James Ricles, Lehigh University; Nicos Makris, Southern Methodist University

Seismic-induced vibrations in civil infrastructure can produce considerable structural damage and loss of life. Supplemental energy dissipation devices have been shown to be an effective method to limit inelastic structural deformations and damage from seismic hazards, therefore enhancing structural resiliency. Recently, a novel pressurized sand damper (PSD) has been developed to enhance structural performance against natural hazards. The PSD utilizes sand as the energy dissipative material which can be implemented in harsh environments with extremely high or low temperatures that may challenge the use of traditional passive fluid dampers.

The presentation will discuss the results of a study using real-time hybrid simulation (RTHS) to investigate the seismic mitigation performance of a single-story cross-laminated timber (CLT) building with PSDs installed in post-tensioned rocking CLT walls. First, the details of the building are presented. Second, the RTHS approach is introduced. The analytical substructure in the RTHS contains the numerical model of a self-centering (SC) rocking post-tensioned CLT structural wall (SC-CLT wall), while two physical PSDs form the experimental substructure. The SC-CLT wall is numerically modeled using a beam element for the CLT wall, a nonlinear truss element for a post-tensioned steel bar, and nonlinear gap elements for the rocking base. Two PSDs are connected on each side at the base of the SC-CLT wall to enhance energy dissipation. The PSDs are designed and manufactured at Southern Methodist University and placed in the Real-time Cyber-Physical Structural Systems Testing Laboratory (RCPSS) lab at the NHERI Lehigh Experimental Facility for conducting the RTHS tests. Finally, the RTHS results under various earthquake excitations are presented. The structure's base shear and inter-story drift from RTHS tests are compared with numerical simulation results from two different configurations, including a conventional CLT shear wall case and the SC-CLT wall without PSDs case. Results show that the PSD produces a significant reduction in the maximum base shear and inter-story drift.

Speaker



Nicos Makris

Professor | Southern Methodist University

ID 608: A Semi-Analytical 3D Linear Tropical Cyclone Boundary Layer (TCBL) Model Driven by Asymmetric Gradient Winds

5:40 PM – 6:00 PM

Author(s): Liang Hu, Univ of notre dame; Ahsan Kareem, Univ of notre dame

"This study develops a semi-analytical linear tropical cyclone boundary layer (TCBL) modeling framework that accounts for asymmetry in gradient winds. Although asymmetric gradient winds are ubiquitous in realistic tropical cyclones, axisymmetric TCBL models and height-resolving column models have often still been employed by neglecting azimuthal advection. To address this limitation, the present study derives and solves a linear 3D TCBL model forced by asymmetric gradient winds while explicitly retaining the wavenumber-1 asymmetry in azimuthal advection. The proposed model is restricted to wavenumber-1 asymmetry, and higher-order harmonics and their nonlinear interactions are not pursued.

The governing primitive equations in a cylindrical coordinate system are first enhanced to accommodate asymmetric gradient winds, leading to asymmetric coefficients and inhomogeneous forcing terms on the right-hand side. Through separation of variables and harmonic decomposition, all asymmetries are expressed as wavenumber 0, 1, and -1 components, which converts the governing equations into six coupled equations in terms of unknown Fourier coefficients. These equations are then reformulated into a matrix system and further simplified by applying coefficient restrictions associated with specific asymmetric structures. Consistently, the bottom boundary conditions are also modified via linearization and harmonic decomposition to account for the asymmetry induced by the asymmetric gradient wind forcing. A central-difference discretization yields a numerical solution in matrix form, allowing the problem to be solved efficiently as a linear system and facilitating future extensions and applications. The formulation is further improved by upgrading the constant eddy diffusivity K to arbitrary height-dependent profiles. In addition, for the previously examined asymmetric gradient wind models, their first-order Fourier coefficients are derived approximately in closed form, enabling direct coupling between the gradient wind parameterizations and the proposed semi-analytical solution.

A series of numerical experiments is conducted to evaluate the proposed model from three perspectives: sensitivity to the top boundary condition, the influence of asymmetric gradient winds, and the performance relative to existing simplified models. Comparisons using top boundary heights of 1500 m and 15000 m demonstrate that the upper boundary selection has a negligible influence on the asymmetric spatial patterns shown in contour distributions. In contrast, a higher top boundary tends to overestimate surface wind speeds, with MAPE (mean absolute percentage error) generally below 6% and decreasing with radial distance. Results further indicate that asymmetric gradient winds influence the simulated boundary-layer wind field through two mechanisms: asymmetry in the governing equation coefficients and in the bottom boundary conditions. The boundary-condition-induced asymmetry dominates surface-wind predictions, producing a surface-wind MAPE of up to approximately 15%, while coefficient-induced asymmetry yields a surface-wind MAPE of up to about 3%; both effects decay rapidly with height. Benchmarking against a 3D nonlinear TCBL model shows that the proposed model reproduces surface-wind asymmetry most consistently among simplified approaches, outperforming an enhanced column model without azimuthal advection and a 3D linear model without asymmetric gradient wind forcing, particularly within 1.5 RMW (radius to maximum winds) and for intense storms with $V_{Max} > 55$ m/s."

Speaker



Ahsan Kareem

Professor | University of Notre Dame

MS 090: 10th Mini-Symposium on 4M (Modeling of Multiphysics, Multiscale, Multifunctional) Engineering Materials and Structures

4:00 PM – 6:00 PM | Location: UMC 415-417

Chair(s): Yong-Rak Kim; Huiming Yin; Chung Song; Jianqiang Wei

Moderators



Huiming Yin

Associate Professor | Columbia University

ID 904: Predictive Modeling of Sediment Erosion Rates under Flow through a Physics-Informed Machine Learning

4:00 PM – 4:20 PM

Author(s): Dong Hyun Kim, Texas A&M University; Yurhee Ahn, Texas A&M University; Yong-Rak Kim, Texas A&M University

The properties of sediment erosion rates are essential for evaluating the safety of hydraulic structures such as levees. Traditionally, these erosion rates have been estimated through laboratory experiments or empirical formulas in Computational Fluid Dynamics (CFD) tools like FLOW-3D, where both are expensive to conduct. To overcome the drawback, this study proposes a physics-informed surrogate machine learning model using the XGBoost algorithm. Toward that, we generated a dataset of 200 FLOW-3D simulation results that include varying hydraulic conditions and soil properties. To reflect the physical characteristics of the model, key dimensionless numbers such as the Froude number (Fr), Shields number, particle Reynolds number (Rep), and relative submergence were used as input variables, along with dimensionless parameters related to sediment transport required for computational modeling. For hyperparameter optimization, a Stepwise Greedy Coordinate Search method was adopted, performing 1,000 iterations per stage. To ensure engineering reliability, the ratio of errors within 10% was set as the primary performance metric. The optimized XGBoost model demonstrated excellent predictive performance, recording a high coefficient of determination (r^2) and a low root mean square error, while the computational cost was vastly reduced. The physics-based machine learning surrogate model presented in this study can replace or supplement the costly experiments and CFD simulation for the prediction of erosion rates of sands subjected to complex hydraulic conditions when soil properties are known.

Speaker



Yurhee Ahn

Ph.D. Student | Texas A&M University

ID 912: Enhanced reliability of nanocomposite sensors with AC method

4:20 PM – 4:40 PM

Author(s): Byung-Wook Kim, Columbia University; Jinming Zhang, Columbia University; Huiming Yin, Columbia University

Nanocomposites offer versatile capabilities for structural health monitoring compared with conventional strain gauges. Their high sensitivity to external strain arises from percolating networks of high-aspect ratio nanotubes. Unlike the strain gauges that are limited to discrete and flat locations, nanocomposites are flexible, conformable to non-planar or discontinuous surfaces, and scalable through solution-based fabrication methods, making them well suited for large-area and irregular infrastructure applications. However, the inherent viscoelasticity of polymer nanocomposites leads to stress relaxation over time, reducing the reliability of repeated measurements in long-term structural health monitoring. In this work, we aim to enhance the measurement reliability of nanocomposites by employing alternating current (AC) characterization, in contrast to conventional direct current (DC) methods that primarily capture resistance changes in deformed networks. AC measurements provide access to frequency-dependent electrical responses, where inductance and capacitance reflect nanotube connectivity, tortuosity, and interparticle spacing within the network. By incorporating these additional electrical parameters, AC methods offer deeper insight into the evolution of nanotube networks under mechanical strain. This approach enables improved interpretation of nanocomposite sensing behavior and supports the development of more reliable, long-term monitoring techniques for infrastructure applications.

Speaker



Byung-Wook Kim

Columbia

ID 955: A Physics and Chemistry-Informed Phase-Field Constitutive Framework for Thermo-Oxidative Aging of Semi-Crystalline Polyimide

4:40 PM – 5:00 PM

Author(s): Marwa Yacouti, University of Colorado Boulder; Santiago Marin Jimenez, University of Colorado Boulder; Maryam Shakiba, University of Colorado Boulder

This work presents a constitutive modeling framework to predict the effects of thermo-oxidative aging on the mechanical response and fracture behavior of polyimide films. The framework couples viscoelastic constitutive behavior with a phase-field fracture formulation to capture aging-induced degradation under prolonged thermal and oxidative exposure. While polyimides are widely used in high-temperature aerospace and electronic applications due to their excellent thermal stability and mechanical performance, long-term exposure to extreme environments leads to progressive degradation that compromises structural reliability. Accurately predicting aging-driven failure mechanisms is therefore critical for assessing their long-term performance.

The proposed model incorporates aging effects through degradation functions that scale the bulk modulus, shear modulus, and fracture energy as functions of evolving physico-chemical properties. These degradation terms are formulated using experimentally measurable metrics, including changes in crystallinity and chemical bond structure, enabling the model to capture key aging phenomena such as stiffness loss and embrittlement. As a result, the framework reproduces the progressive deterioration in mechanical performance and fracture resistance observed in aged polyimide films.

The model is developed and validated using experimental data from PMDA-ODA polyimide films aged in air at 300°C for up to five weeks. Mechanical and fracture behavior were characterized through uniaxial tensile and single-edge notch tension tests, while Raman spectroscopy and X-ray diffraction were used to track molecular-level changes. These data informed the calibration and validation of the constitutive framework.

The resulting model provides a predictive tool for assessing the long-term mechanical integrity and failure of polyimide-based components operating under extreme environmental conditions.

Speaker



Marwa Yacouti

Graduate Research Assistant | University of Colorado Boulder

ID 1029: From Idealized to Realistic Pores: Phase-Field Fracture Modeling of Porous Materials

5:00 PM – 5:20 PM

Author(s): Ryan Nielsen, University of Utah; Pania Newell, University of Utah

Porous materials exist and function in a myriad of settings, from ceramics, foams, bones, concrete, and wood, to filtration membranes, battery components, and insulation. Porous materials typically couple the structural rigidity of their solid component with some secondary function attributable to their microstructural voids. However, porous materials are also susceptible to brittle fracture, a failure mode characterized by rapid crack propagation without warning. Given their ubiquitous prevalence in both nature and infrastructure, accurate failure prediction of such materials is of the utmost importance. While many works have examined both the effect of pore shape on constitutive behavior and how fracture can be modeled as a 2-scale problem, no works have examined how realistic and idealized pore shapes affect macroscale fracture behavior. This work investigates how an underlying microstructure consisting of either idealized or realistic pore shapes affects fracture resistance and path. A 2-scale solution strategy is employed in which a homogenized or effective constitutive tensor is computed via the asymptotic homogenization method and mapped to a macroscale brittle fracture problem. The effective constitutive tensor conveys macroscale material anisotropy induced by the underlying microstructure. The macroscale fracture mechanics problem is modeled via the phase-field method, which is a variational formulation of the Griffith energy balance. Crack advancement is controlled by a functional consisting of competing energy storage terms: internal strain energy and potential energy of the crack surface. As such, any change in microstructure corresponds to a change in strain energy and thus fracture results. To test this thesis, the effective constitutive tensor for numerous instances of both idealized and realistic pore structures is mapped to a phase-field model of an edge-cracked plate in tension. The resultant force-displacement curves and crack paths for 8 realistic and 8 realistic morphologies show that realistic-pore scenarios provide a more compliant response and, as such, a delayed onset in crack propagation.

Speaker



Ryan Nielsen

Mechanical engineer | Williams international

ID 914: Influence of Composition on Calcium Silicate Hydrate: from Atomic Structure to Macro-Performance

5:20 PM – 5:40 PM

Author(s): Jianqiang Wei, University of Maryland, College Park

Calcium silicate hydrate (C-S-H) is the principal binding component in hydrated cement, governing the strength, shrinkage, and durability of cement paste and concrete. The unique stoichiometry and molecular structure of C-S-H enable the incorporation of additional constituents and adjustment of elemental ratios, leading to significant changes in its morphology and properties. The roles of two primary elements, calcium (Ca) and silicon (Si), as well as their molar ratios, in regulating C-S-H remain essential for advancing cement chemistry and tailoring next-generation binders. A multiscale characterization framework is employed in this study to examine how reaction kinetics, phase evolution, molecular configuration, and structure-property relationships vary across $\text{CaO-SiO}_2\text{-H}_2\text{O}$ systems with Ca/Si ratios between 0.8 and 2.0, targeting controlled formation of C-S-H(I) and C-S-H(II). Moving beyond microscale analysis, two key C-S-H properties, dynamic moisture sorption and mechanical performance, were assessed, revealing direct connections among composition, nanoscale structure, and macroscopic response. The results show that a low Ca content within the C-S-H(I) regime is thermodynamically favorable for shortening induction periods, accelerating reaction kinetics, and enabling early-age C-S-H formation through enhanced silicate polymerization and Si-O-Si connectivity. Increasing the Ca/Si ratio, however, can lead to progressive silicate chain shortening, stronger Ca-related correlations, and reorganization of the medium-range amorphous network with modified density, which increases moisture sorption capacity but reduces mechanical strength. It is anticipated that the findings from this study will provide new insights into the structure-property relationships of C-S-H, advancing the fundamental understanding of cement chemistry and guiding the design of sustainable cementitious composites.

Speaker



Jianqiang Wei

Assistant Professor | University of Maryland

ID 237: Coupled Shrinkage and Hydro-Mechanical Behavior of Carbon Fiber-Reinforced Bentonite

5:40 PM – 6:00 PM

Author(s): Yuan Feng, University of Maryland; Jongwan Eun, University of Maryland; Semih Ciftci, University of Maryland

Bentonite-based barrier materials are widely used in geoenvironmental containment systems; however, their performance is frequently limited by shrinkage-induced cracking during drying. This study investigates the coupled shrinkage, deformation, and hydraulic behavior of carbon fiber-reinforced bentonite using full-field deformation measurements and soil-water characteristic analysis. Controlled drying tests were conducted on bentonite specimens with varying carbon fiber contents. Digital image correlation (DIC) was used to quantify strain evolution, shrinkage anisotropy, and crack initiation and propagation. Results show that carbon fiber inclusion substantially reduces shrinkage strain and suppresses crack development by promoting stress redistribution and internal reinforcement. Unreinforced bentonite exhibits pronounced strain localization preceding crack formation, whereas fiber-reinforced specimens display more uniform and distributed deformation. Soil-water characteristic curves indicate that fiber reinforcement increases water retention and modifies air-entry values, suggesting changes in pore structure and suction response. Together, the mechanical and hydraulic results demonstrate that carbon fibers alter the hydro-mechanical response of bentonite under desiccation, improving dimensional stability and resistance to drying-induced damage. These findings support the use of carbon fiber-reinforced bentonite as an engineered barrier material with enhanced durability under high-suction conditions.

Speaker



Jongwan Eun

Associate Professor | University of Maryland

MS 091: Advances in Modeling of Material Damage and Fracture

4:00 PM – 6:00 PM | Location: UMC 382-384-386

Chair(s): Mostafa Mobasher; Lampros Svolos; Aditya Kumar; Georgios Moutsanidis; Alessandro Fascetti; Ravindra Duddu; Haim

Moderators

**Mostafa Mobasher**

Assistant Professor | New York University Abu Dhabi

ID 493: Phase-Field Modeling of Fracture in Multiphase, Rate- and Temperature-Dependent Materials

4:00 PM – 4:20 PM

Author(s): Rogelio Muneton-Lopez, University of Missouri; Oliver Giraldo-Londono, University of Missouri

The phase-field method has emerged as a robust and versatile framework for modeling arbitrary fracture propagation in solids. While recent developments have incorporated viscoelastic and thermo-mechanical effects, most existing approaches either assume material homogeneity or represent heterogeneity only through spatial variations of material properties while preserving the same constitutive behavior across phases (e.g., elastic bulk material behavior). Such representations may be inadequate for heterogeneous materials such as asphalt concrete, which is composed of various constituents (e.g., mastic and aggregate phases) with fundamentally different time-dependent behavior. Neglecting this heterogeneity limits our ability to capture key fracture mechanisms, including crack deflection, tortuosity, and phase-dependent energy dissipation, which directly influence the macroscopic fracture response.

To address these limitations, we introduce a phase-field modeling framework that explicitly accounts for material heterogeneity and phase-dependent constitutive behavior. The proposed framework enables a realistic representation of multiphase materials by assigning distinct mechanical responses to individual material phases, enabling the unified modeling of rate-dependent and rate-independent mechanisms in multiphase materials. The formulation employs a weakly coupled thermo-viscoelastic approach wherein temperature changes produce deformations due to thermal expansion or contraction, but mechanical deformations do not produce temperature variations. To solve for the displacement field, effective stresses are evaluated recursively, with stresses at the current time step computed from those at the previous time step, thereby avoiding the explicit evaluation of hereditary convolution integrals. Phase-field evolution is governed by a weighted crack-driving force that accounts for contributions from the elastic energy of the system, in addition to viscous dissipation associated with time-dependent mechanisms.

In this presentation, we provide details of the formulation and present several numerical examples that demonstrate the ability of the proposed framework to predict complex crack paths in heterogeneous media. We also compare the results predicted by our model against experimental results to assess its predictive capability. The findings from this work underscore the importance of explicitly representing material heterogeneity in fracture models as a means of improving their predictive capability under thermo-mechanical loading.

Speaker**Rogelio Muneton**

Graduate Student | University of Missouri

ID 597: Why planar cracks fragment into echelon cracks

4:20 PM – 4:40 PM

Author(s): Aditya Kumar, Georgia Institute of Technology; Olivia Ward, Georgia Institute of Technology

Understanding the growth of large cracks in brittle materials is the most fundamental problem in fracture mechanics.

Under out-of-plane shear loading, an initially planar crack may fragment into multiple cracks, forming an echelon crack pattern. Explaining this phenomenon is essential for developing a general theory of crack growth. Although numerous empirical criteria have been proposed in the literature, none provide a unified explanation of all observed features and are largely restricted to two-dimensional growth in linear elastic isotropic materials. In this talk, we confront a classical set of echelon crack growth experiments using two phase-field approaches: the classical variational model and a strength-constrained model.

We show that, contrary to prevailing views, the variational model based solely on Griffith's energetic competition between elastic and fracture energies is fundamentally incomplete even for predicting the growth of large cracks. By incorporating a material strength surface that constrains the regions in which a crack can grow, the resulting model accurately predicts echelon crack growth without invoking any ad hoc assumptions about material or geometrical disorder. Results are presented for both soft and hard materials, confirming the model's general applicability to any brittle material.

We further identify two governing non-dimensional parameters that control crack orientation and morphology and demonstrate that one of them, the ratio of shear to tensile strength, determines whether crack paths are more influenced by energy-based or stress-based empirical criteria, thereby reconciling these criteria within a single framework.

Speaker**Aditya Kumar**

Assistant Professor | Georgia Institute of Technology

ID 625: Strength-Based Orthotropic Phase-Field Fracture Model for 3D-Printed Materials

4:40 PM – 5:00 PM

Author(s): Bishal Koirala, University of Vermont; Lampros Svolos, University of Vermont

Additive manufacturing, also known as three-dimensional (3D) printing, represents a paradigm shift in engineering applications due to its innovative approach to fabricating objects. It provides several advantages, particularly in rapid prototyping and the production of customized components. Predictive modeling of fracture in 3D-printed materials is crucial for preventing failure under service loading conditions in high-performance mechanical applications. Materials produced via fused deposition modeling (FDM) exhibit anisotropic mechanical behavior, with physical properties that vary along different loading directions. They often display orthotropic behavior due to their layer-by-layer deposition, resulting in crack growth that is highly influenced by the orientation of material layers. Accurately modeling orthotropic fracture remains one of the most challenging problems in the field of computational mechanics.

Traditional fracture-mechanics methods represent cracks as sharp discontinuities, making their implementation in the Finite Element Method (FEM) challenging. The phase-field fracture (PFF) method describes crack topologies using a continuous field, allowing the simulation of complex fracture phenomena, such as propagation, branching, and merging, without explicit crack tracking. Although PFF methods are highly effective in predicting complex crack propagation, their inherently energy-based formulation limits their ability to accurately capture crack nucleation, particularly in the absence of pronounced stress concentrations or pre-existing defects.

In this talk, we present a novel strength-based phase-field fracture model that incorporates a Tsai-Wu failure criterion to capture crack nucleation in orthotropic materials. Orthotropy is incorporated consistently through direction-dependent stiffness, material strength, and fracture energy using a physics-based structural tensor. The proposed framework is verified using representative numerical examples and validated through comparisons with experimental fracture data, demonstrating improved predictions of fracture initiation and evolution in orthotropic materials.

Speaker



Bishal Koirala

Graduate Student | University of Vermont

ID 197: A full-Stokes phase field fracture model for simulating creeping flow and brittle fracture of glaciers

5:00 PM – 5:20 PM

Author(s): Ashvin Oli, Vanderbilt University; Tim Hageman, University of Oxford; Abhinav Gupta, Vanderbilt University; Ravindra Duddu, Vanderbilt University

Iceberg calving driven by fracture processes is a dominant mechanism of mass loss from glaciers and ice sheets, yet it is poorly understood, contributing to significant uncertainty in ice sheet model projections. Simpler calving models evaluate crevasse depths using linear elastic fracture mechanics and zero stress theories and are easy to implement within ice sheet models ; however, they cannot describe the complex feedback between thermo-visco-elastic ice flow and brittle fracture, which is important to gain process-level understanding and to reliably predict calving outcomes. In this talk, we present a novel ice flow and fracture formulation by combining the nearly-incompressible Stokes model with temperature-dependent non-Newtonian viscous ice rheology (Jimenez et al. 2017) and the stress-based phase field fracture model (Nguyen et al., 2025). The proposed formulation built in the open source software FEniCS offers a robust framework to capture both the nucleation and propagation of fractures in a diffuse manner while preserving the underlying physics of ice flow and accounting for the tension-compression asymmetric behavior of ice. First, we will describe the governing equations of the formulation including the modified nearly-incompressible Stokes flow equations that considers the degradation of viscosity based on the phase-field/damage variable. Second, we will present a benchmark simulation of crack growth in a plate with a central hole under uniaxial compressive loading and show the agreement in the crack pattern between linear elastic and nonlinear viscous constitutive models formulations. Third, we will demonstrate the robustness of the new full-Stokes phase field fracture formulation by conducting simulations with single and multiple crevasses, and by exploring the sensitivity of model predictions to mesh size and length scale.

Jiménez, S., Duddu, R., & Bassis, J. (2017). An updated-Lagrangian damage mechanics formulation for modeling the creeping flow and fracture of ice sheets. *Computer Methods in Applied Mechanics and Engineering*, 313, 406-432.

Nguyen, D. T., Gupta, A., Duddu, R., & Annavarapu, C. (2025). An adaptive mesh refinement algorithm for stress-based phase field fracture models for heterogeneous media: Application using FEniCS to ice-rock cliff failures. *Finite Elements in Analysis and Design*, 244, 104311.

Speaker



Ashvin Oli

Mr. | Vanderbilt University

ID 675: Efficient Phase-Field Fracture Modeling Using the I-FENN Framework

5:20 PM – 5:40 PM

Author(s): Lampros Svolos, University of Vermont; Prakash Dulal, University of Vermont; Panos Pantidis, New York University Abu Dhabi; Diab Abueidda, New York University Abu Dhabi; Mostafa Mobasher, New York University Abu Dhabi

The Integrated Finite Element Neural Network (I-FENN) framework was developed as a numerical paradigm for simulating coupled mechanical systems by incorporating machine learning techniques into the finite element method (FEM). In this framework, the key idea is to numerically integrate the equilibrium equations using the well-established FEM, while the remaining governing equations of the problem are solved using pre-trained neural networks (NNs). This approach offers high efficiency and robustness, as demonstrated in various multiphysics settings (e.g., non-local continuum damage mechanics and thermoelasticity problems).

In this talk, we extend the I-FENN framework to efficiently simulate fracture-mechanics problems using the phase-field method. First, we present the governing equations of the system, in which cracks are represented with the aid of a bounded, continuous field (the so-called phase field). Second, we train a physics-informed convolutional neural network (PI-CNN) using a minimal set of input samples to infer the phase-field variable based on the crack-driving force in the phase-field equation. We show how the pre-trained PI-CNN can be reused and integrated into staggered FEM-based solvers on both structured and unstructured meshes. Finally, we examine the accuracy and efficiency of I-FENN against several benchmark problems from the literature, including single- and multiple-crack domains in heterogeneous materials under varying loading conditions.

Speaker



Lampros Svolos

Dr. | University of Vermont

ID 780: Arbitrary-order virtual element methods for high-order phase-field modeling of ductile fracture

5:40 PM – 6:00 PM

Author(s): Yu Leng, Los Alamos National Lab; Hashem Mourad, Los Alamos National Laboratory

Accurate modeling of fracture in ductile materials subjected to dynamic loading conditions is important in a wide range of application areas. Second-order phase-field fracture models have gained wide acceptance given their ability to capture the formation of complex fracture patterns, and their suitability for implementation within the context of the conventional finite element method. Higher-order phase-field models introduced in recent years lead to a higher-regularity exact solution, and thus higher spatial convergence rate with mesh refinement. However, they require special numerical techniques, such as the virtual element method (VEM), to preserve the higher regularity of the phase field solution. The VEM, which is a generalization of the finite element method, also allows computations to be conducted on meshes of general polytopal elements.

In this work, we adapt a VEM framework that we previously developed for brittle fracture problems, and apply it here to problems involving plastic deformation and dynamic ductile fracture. We use H1-conforming virtual elements and generalized- α method for the momentum conservation equation, and H2-conforming virtual elements for the fourth-order phase-field equation. The material behavior is represented using an elastic-viscoplastic material model. We first study shear localization problems without fracture and then show numerical examples involving dynamic ductile fracture.

Speaker



Yu Leng

Los Alamos National Laboratory

MS 094: Mechanics and Physics of Granular Materials

4:00 PM – 6:00 PM | Location: VAC 1B20

Chair(s): Ryan Hurley; Marcial Gonzalez; Yimin Lu; Dawa Seo; Alessandro Rotta Loria; Ali Daouadji

Moderators



Dawa Seo

Dr. | Wayne State University

ID 513: High and low-speed penetration of “architected” FCC granular crystals: Experiments and models

4:00 PM – 4:20 PM

Author(s): Ashta Navdeep Karuriya, University of Colorado Boulder; Francois Barthelat, University of Colorado Boulder

Typical granular materials have rich and complex mechanics and physics, but they are far from optimal in terms of mechanical performance: Random packing and poor load transfer between individual grains result in low strength, brittleness and strain localization. In this project we are taking a new approach to granular materials as a platform for “architected” systems: We used mechanical vibrations to assemble 3D printed rhombic dodecahedral grains into fully dense FCC granular crystals confined in a container and interacting by frictional contact only. We then performed sharp penetration tests on the surface of these crystals at quasi-static speeds (on standard loading frame) and at impact speeds (using a drop impact tower). The tests revealed that these granular crystals are more than 1000 times “harder” than randomly packed spheres (RPS, representative of typical noncohesive sand), with unique “explosive” failure modes even under quasi-static loading. These materials also showed high energy dissipation capacity: their energy absorption was up to 100 times higher than RPS. Using experiments and discrete element models, we show that despite the high mechanical confinement of the crystals, frictional sliding along specific slip planes is a prominent deformation mechanism up to the failure of the uppermost layer of grains. As the indenter is “wedged” between the grains, large compressive forces develop in the transverse directions, which eventually leads to the sudden buckling of the uppermost layer of grains, and to “explosive” failures involving the ejection of grains. As penetration proceeds, this loading-buckling cycle repeats, as layers are defeated in sequence. We finally show that once the surface layers of the crystal are destroyed by the penetrator, the crystal can be “healed” with vibrations and then punctured again with no loss of mechanical performance. These granular “metamaterials” can serve as platform to develop additional strengthening strategies inspired by metallurgy, and they can find applications for rapid and versatile construction of static structures or as light weight protective materials in a multitude of applications (e.g. buildings, body armor, vehicles, etc.).

Speaker



Ashta Navdeep Karuriya

Dr. | University of Colorado Boulder

ID 521: Impact mechanics of FCC granular crystals: Experiments and models.

4:20 PM – 4:40 PM

Author(s): Armin Yousefi, University of Colorado Boulder; Francois Barthelat, University of Colorado Boulder

Granular materials can be defined as large collections of discrete, macroscopic particles that are generally non-cohesive. Although these materials appear simple, they exhibit a wide range of complex mechanical responses, which makes them important both in everyday life and in industrial applications such as food processing, pharmaceuticals, powder metallurgy, geology, and mining. In this study, millimeter-scale rhombic dodecahedral grains were assembled into fully dense face-centered cubic (FCC) lattices using mechanical vibrations, and then infiltrated with an adhesive to form free-standing FCC crystals. These granular crystals display a rich set of deformation mechanisms, including nonlinear elasticity, crystal plasticity reminiscent of atomistic mechanisms, and geometric strain hardening under quasi-static compression.

Here, we investigated the mechanics of FCC granular crystals subjected to impact loading. A two-meter drop impact tower was mounted with acrylic input and output bars instrumented with strain gauges, and modified to increase maximum impact speed. In addition to input and output force histories, high-speed imaging was used to track individual grains during impact. Using these methods, we identified a transition of failure mode from $\{111\}$ slip dominated macroscale plasticity at slow loading rates to homogenous and large deformations behind a plastic wave at higher impact rates. Force histories and imaging were used to measure the elastic wave speed and the plastic wave speed in the granular crystals, which were consistent with classical models for elastic-plastic materials subjected to 1D impact. We also found that the compressive strength of the crystal when loaded at high rates is 5 to 30 times higher than at quasi-static rates, which we attributed to microinertia effects, frustration of energetically favorable $\{111\}$ slip mechanisms, and the rate dependence of the adhesive used to bond the grains. Discrete elements models were used to capture the failure mode transitions, and to explore the interplay between grain geometry, intergranular adhesion, and microinertia. These granular crystals can serve for strong, impact absorbing structures. In addition, individual grains can be cleaned and used again to create fresh materials, so that these granular crystals can be used to create modular and recyclable structures.

This work is supported by the Army Research Office under Grant Number W911NF-24-2-0126.

Speaker



Armin Yousefi

Cu Boulder

ID 614: Exotic Metamaterials Conceived using Granular Micromechanics

4:40 PM – 5:00 PM

Author(s): Anil Misra, Florida International University

This presentation will discuss the salient features of exotic metamaterials and granular motifs. We will describe how granular micromechanics serves as an engine for conception of exotic metamaterials of granular motif [1-3]. Such metamaterials follow a motif inspired by granular material system that may be defined as those composed of nearly rigid elements (or grains) in which the strain energy is stored/dissipated in deformable interconnections or interfaces between the grains. Indeed, granular materials are examples of materials systems that exhibit a range of behavior that have defied descriptions based upon either classical continuum or discrete models. GMA provides a paradigm of heuristic micro-macro analysis to link microscale mechanisms to macroscale response. Here we exploit this analysis to design and fabricate 1D and 2D metamaterials with prescribed grain-pair interactions (see for example [4-8]). The microscale deformation of these metamaterials was analyzed using digital image correlation (DIC) particularly in relation to the grain motions and the emergent non-standard macro-scale response.

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Speaker



Anil Misra

Professor and Chair | Florida International University

ID 808: Micromechanical origins of changes in shear localisation in cemented sands

5:00 PM – 5:20 PM

Author(s): Anne-Catherine Dieudonné, Delft University of Technology; Aoxi Zhang, Zhejiang University; Antoine Wautier, INRAE; Frédéric Collin, University of Liege

Bio-cementation by microbially (or enzymatically) induced carbonate precipitation can markedly increase the stiffness and peak strength of granular soils. Yet, experiments also report a counterintuitive trend: some treated sands exhibit lower residual strength than the uncemented material at large strains. In many geosystems and earth structures, stability is governed by the residual state that emerges once deformation localises onto shear surfaces. Pinning down the conditions under which residual weakening occurs therefore requires linking macroscopic post-peak response to the evolving mesoscale organisation of contacts, force chains, and kinematics.

We use discrete element method (DEM) simulations in which sand grains and calcium carbonate particles are modelled explicitly, enabling cement to occupy pore space rather than being reduced to contact "virtual bonds." We focus on a grain-bridging precipitation pattern (carbonates connecting grains that were not initially in contact) and perform drained biaxial tests in 2D, supported by companion 3D results. A parametric campaign varies carbonate content, sand-carbonate cohesive strength, the stiffness contrast between carbonate and sand, and confining pressure.

The results show that grain bridging does not impose a unique residual outcome: the residual state may be weaker or stronger than the uncemented reference depending on the competition between localisation-driven degradation and bond-supported load transfer. Residual strength is governed primarily by the cohesive strength at sand-carbonate contacts and by the stiffness contrast between carbonate and sand, while carbonate content (within the studied range) and confining pressure play secondary roles. Kinematic fields reveal a transition from diffuse deformation in uncemented (and low stiffness contrast) cases to early strain localisation and mature shear bands when bridging contacts are prone to instability, for example in weakly cemented packings combined with relatively stiff carbonate. Grain-scale stability analyses and bond-breakage mapping indicate that bridging carbonates modify the contact structure and can introduce metastable configurations that promote relative sliding and rolling, concentrating damage within the band. Inside the band, stress rotation and reduced mean stress accompany intensive bond breakage, rationalising the macroscopic softening and potential residual weakening.

Overall, residual behaviour in bio-cemented granular media emerges from a mesoscale competition: bond-induced stabilisation through retained cohesive bridges versus instability-driven localisation and restructuring. This framework helps reconcile disparate experimental trends and points to precipitation pattern as a key control, with combined patterns, especially contact cementation, offering a route to retain peak gains without residual weakening.

Speaker



Anne-Catherine Dieudonné

Associate Professor Multiphysics Geomechanics | Delft University of Technology

ID 886: A Micromechanics-based Hyperelastic Framework for Anisotropic Granular Materials

5:20 PM – 5:40 PM

Author(s): Hongwei Wu, Northwestern University; Giuseppe Buscarnera, Northwestern University

Granular materials exhibit adaptive elastic anisotropy, where small-strain stiffness evolves with stress state and fabric arising from the shape and arrangement of their particles. Yet, most existing micromechanical formulations rely on strong idealizations, such as spherical particles and linear contact laws. This work develops a micromechanics-based hyperelastic constitutive framework for granular assemblies consisting of general particle shapes and morphology-dependent nonlinear deformation properties at their contacts. The goal is to clarify the particle-scale origins of adaptive elastic anisotropy and provide a computationally efficient alternative to discrete element method (DEM) for engineering-scale analyses. The model is derived from a thermodynamically consistent energy formulation, obtained by summing the complementary energy stored at interparticle contacts. The derivation naturally introduces four fundamental fabric descriptors: branch vector orientation, branch length, contact normal orientation, and effective contact radius. Fabric distributions are approximated with one-parameter Fourier series, capturing both inherent and stress-induced anisotropy. The framework is then validated using DEM simulations of assemblies consisting of spheres, ellipsoids, and virtual replicas of Leighton Buzzard sand grains reconstructed from μ -CT data. Using DEM simulation results as a benchmark, it is shown that the continuum model reproduces satisfactorily the key anisotropic elastic properties of the considered granular systems for a range of void ratio and confining pressure, while keeping the computational cost reasonably low. The analyses further indicate that the branch length and the contact radius distribution are nearly stress-invariant, whereas the branch orientation and the contact normal distribution evolve with the stress ratio, making them primary drivers of stress-induced anisotropy together with the nonlinearity of the contact law. Finally, the study examines commonly used linear cross-anisotropic parameter correlations, revealing that they are valid only at low anisotropy levels. A global sensitivity analysis further demonstrates that geometric fabric anisotropy dominates the macroscopic response, while stress anisotropy plays a secondary role. The proposed framework advances mechanistic understanding of adaptive anisotropy in granular media and offers guidance for designing particulate materials with tailored elastic anisotropy.

Speaker



Hongwei Wu

Mr. | Northwestern University

ID 491: Choosing the appropriate multiphase lattice Boltzmann approach for simulating pore-scale fluid distributions in unsaturated granular soils

5:40 PM – 6:00 PM

Author(s): Reihaneh Hosseini, Virginia Tech; Clara Toffoli, Hamburg University of Technology.

Multiphase (wet) granular materials, including unsaturated soils, are ubiquitous in both natural and industrial settings. The complex macroscopic behavior of these materials is closely linked to the distribution of fluids, typically water and air, within their pore space. This fluid distribution governs the magnitude of capillary forces, which in turn influence grain interactions and the overall macroscopic response. Consequently, significant insight into the behavior of such materials can be gained by studying pore-scale fluid distributions. Given the experimental challenges associated with capturing these distributions, pore-scale numerical modeling provides a valuable alternative. Among the available pore-scale modeling techniques, the lattice Boltzmann method (LBM) has attracted widespread attention due to its simplicity and computational efficiency. Several extensions of single-phase LBM to multiphase flow have been proposed. Of these, the multicomponent Shan–Chen, multiphase Shan–Chen, and He–Chen–Zhang models are the three primary approaches that have been employed to simulate unsaturated soils. However, in most previous studies, the choice of method has been made without explicit justification. This raises the question of which approach is most suitable for this specific application. In this study, these three methods are implemented in an in-house code and carefully calibrated to ensure consistent interfacial physics across all models. They are then used to simulate drainage and imbibition processes in a two-dimensional granular packing. Furthermore, a simple 3D-printed physical model of the granular packing is used as a qualitative benchmark. The results of the three methods are compared quantitatively in terms of the captured suction and saturation at different stages of drainage and imbibition, and qualitatively with respect to pore emptying mechanisms and predicted fluid distributions based on graphical visualization. Finally, the methods are compared in terms of computational cost. Based on these comparisons, recommendations are made regarding the most suitable method for simulating quasi-static, capillarity-dominated processes in unsaturated granular soils.

Speaker



Reihaneh Hosseini

Research Assistant Professor | Virginia Tech

MS 100: Computational Geomechanics

4:00 PM – 6:00 PM | Location: HUMN 1B80

Chair(s): Hyoung Suk Suh; Shabnam Semnani; Jinhyun Choo; WaiChing Sun; Craig Foster; Richard Regueiro; Ronaldo Borja

Moderators



Hyoung Suk Suh

Assistant Professor | Case Western Reserve University

ID 422: Computational Modeling and Validation of Wave Barriers for Mitigating Train-Induced Vibrations

4:00 PM – 4:20 PM

Author(s): Isaac Banes, University of Illinois Chicago; Kanishka Kolhatkar, University of Illinois Chicago; Ryan Shin, University of Illinois Chicago; Craig Foster, University of Illinois Chicago

As transport by rail continues to grow in both the U.S. and in Europe, there is an incentive to develop efficient means for mitigating rail-induced vibration in structures near railways. Train-induced vibrations may lead to discomfort in nearby residents as well as decreased property value. Furthermore, adverse health outcomes may arise in residents near train tracks due to long-term exposure to train-induced vibrations. Therefore, developing effective models to test vibration mitigation measures is important. Testing vibration mitigation measures via large scale test sites can be costly, hence developing computational models can be an effective way to test various measures. As these models can be quite large and involved, improving the computational time would greatly benefit testing and analysis.

Two detailed finite element models are created in ANSYS based on empirical tests performed in the literature that examined wave barriers as mitigation measures for train-induced vibrations. One test site examined the efficacy of the wave barrier in damping vibrations beyond the barrier, while the other test site examined the vibrations beyond the wave barrier in a test building frame. These test sites are recreated as computational domains with detailed modeling in order to capture the real-world physics accurately. The rails are modeled using cubic beam elements and the remaining geometry is modeled using quadratic tetrahedral and hexahedral elements. After testing the model to ensure mesh-independence, modal data is extracted from both models and imported into SIGMA/SAMS. SIGMA/SAMS is a multibody dynamics code that accurately models the interactions between the wheels and rail using the Floating Frame of Reference formulation, which avoids the need to model the interaction in the finite element model. A transient multibody dynamics simulation is then run using only modal data for the rail. This allows for complex models to be created that can be solved efficiently by exporting a small amount of modal data, solving in the multibody code, and then reconstructing the results in the full model by converting the modal displacements and accelerations back to nodal form. This method greatly improves on the simulation time for the problem while accurately modeling the complex wheel-rail interactions and predicting the vibrations in nearby buildings and soil that may result from these interactions.

Speaker



Isaac Banes

PhD Student | University of Illinois at Chicago

ID 735: A phase-field model for fractured poroelastic rocks under cyclic fluid injection

4:20 PM – 4:40 PM

Author(s): Sabrina CY Ip, Lawrence Berkeley National Laboratory; Mengsu Hu, Lawrence Berkeley National Laboratory

Fracture connectivity for fluid flow is essential in many subsurface energy applications, including oil and gas, enhanced geothermal and geological hydrogen systems. Poroelastic stress changes induced by fluid injection can play a fundamental role in hydraulic fracturing, fracture reactivation and permeability evolution. Cyclic injection strategies have been considered as a method to enhance reservoir performance by mitigating induced seismicity while enhancing permeability. However, the underlying mechanisms of how cyclic injection can enhance permeability are not well-understood. Simulating the effects of cyclic injection on fracture permeability in a poroelastic matrix requires consideration of the complex interactions between hydraulic and mechanical processes as well as evolving fracture properties, making the problem difficult to model. Phase-field models have emerged as an effective technique for fracture modeling as they do not require explicit tracking of the crack propagation and can easily incorporate multiphysics coupling. In this study, we investigate the effects of poroelasticity on fracture propagation and permeability evolution under cyclic injection using a hydromechanical phase-field framework for hydraulic fracturing. A variety of injection strategies are simulated to explore the influence of injection volume, rate and frequency across permeability contrasts. We compare the behavior of hydraulic fracturing in high and low permeability reservoirs, and also consider serpentine-filled fractures as obtained from real samples. Numerical simulations reveal that cyclic injection promotes distributed fracture propagation, while the Biot coefficient controls the spatial extent of injection-induced poroelastic stresses. These results highlight the importance and regimes of poroelastic effects on fracture behavior under cyclic injection and provide insight into reservoir stimulation design for cyclic injection strategies.

Speaker



Sabrina Ip

Postdoctoral Scholar | Lawrence Berkeley National Laboratory

ID 794: Considerations in Development of Ground Movement Prediction by Tunnel Boring Machine - Ground Interaction Digital Twins

4:40 PM – 5:00 PM

Author(s): Joseph Verkler, Colorado School of Mines

Numerical digital twins of tunnel boring machine (TBM) – ground interaction have the potential to reduce risk of ground deformation that can cause infrastructure damage. To simulate complex soil behavior induced during tunnel excavation, an advanced constitutive model is required. However, in practice the available site investigation data is rarely sufficient to fully develop parameters for these models.

Consequently, parameters are commonly calibrated through back-analysis of surface displacement monitoring data. Due to the high dimensionality of advanced soil models, tuning parameters are selected as the influential parameters identified by sensitivity analysis. While this approach is widely used, parameter influence is commonly evaluated solely based on predicted ground deformations. The internal constitutive responses of the model, such as stress-path evolution and yield mechanisms, are rarely examined. As a result, some parameters may appear insensitive only because of the chosen geometry or values of other parameters. Parameters deemed insensitive under one set of conditions may quickly become sensitive as conditions vary along a tunnel alignment.

This presentation investigates stress-path behavior and constitutive model response in the vicinity of a tunnel interface. A numerical digital twin of the Shoreline Storage Tunnel (SST) Project is developed in FLAC3D to examine the effects of geometry, stratigraphy, and constitutive model selection. Several commonly used constitutive models are evaluated, and individual parameter influence is assessed by visualizing stress paths. The simulation is varied by uncertainties in geotechnical inputs and soil deposition to showcase potential changes in conditions along a TBM alignment.

Results show that parameter sensitivity can change rapidly along a typical tunnel alignment. Parameters that appear insensitive when evaluated using surface deformation alone may exert strong control over internal constitutive response under different soil and geometric conditions. These findings highlight limitations of conventional sensitivity analyses and provide guidance on constitutive model selection and parameter calibration strategies for more reliable TBM digital twins.

Speaker



Joe Verkler

PhD Student | Colorado School of Mines

ID 803: Validation of Numerical Models to Simulate Robotic Muscle Actuation in Soil

5:00 PM – 5:20 PM

Author(s): Austin Hoyle, Colorado School of Mines; Hyun-Woo Joo, Colorado School of Mines; Mike Mooney, Colorado School of Mines

This work presents a combined experimental and computational investigation aiming to validate commonly used soil constitutive models for robot–soil interaction problems involving large deformation. We radially expand a bio-inspired robotic muscle embedded in a laboratory soil test bed, representative of actuation mechanisms commonly used in burrowing and anchoring robotic systems. A novel experimental framework is developed in which the soil surrounding the expanding muscle is instrumented with mechanically embedded displacement sensors. This enables direct time dependent measurements of the radial soil deformation during expansion as a function of distance from the cavity. These measurements allow reconstruction of the evolving near-field displacement response as a function of muscle pressure. Following the experimentation, we measure elastic and plastic properties of the test soils and calibrate the Mohr–Coulomb and Modified Cam Clay plasticity models using the ABAQUS finite element software. Numerical simulations are then performed in an attempt to model the experimental expansion process. Cylindrical cavity expansion theory (CET) is additionally employed to analytically model the experimental pressure–expansion response, as the muscle expansion induces an axisymmetric radial deformation field in the surrounding soil. However, due to the finite length of the muscle and its axial contraction during expansion, the experimental process violates the plane strain assumption inherent to classical cylindrical CET formulations. As such, CET is treated as a first-order reference. The numerical and CET results are evaluated by direct comparison of predicted near-field displacement and/or muscle pressure–expansion response against the experimentally measured data. Through these comparisons, this work establishes an experimentally grounded validation framework for assessing the ability of numerical soil constitutive models to predict soil behavior during subsurface robotic muscle expansion and provides insight into the applicability and limitations of widely used constitutive models in computational geomechanics for robot–soil interaction problems.

Speaker



Austin Hoyle

PhD Researcher | Colorado School of Mines

ID 1026: Forecasting land subsidence due to groundwater withdrawal in the San Joaquin Valley, California and in Yunlin, Taiwan

5:20 PM – 5:40 PM

Author(s): Ronaldo Borja, Stanford University; Yangqing Sun, Stanford University; Chih-Yu Liu, National Taiwan Ocean University; Nan-Chieh Chao, National Cheng Kung University; WeiCheng Lo, National Cheng Kung University

Groundwater withdrawal is known to cause land subsidence in the San Joaquin Valley, California and in Yunlin County, Taiwan. Time-history records in the two regions reveal that when the groundwater level dropped, the land surface experienced subsidence, and when the water level rose, the land surface experienced a smaller upheaval, leaving a net downward movement after each cycle. While this trend is to be expected, the subsidence in both regions inexplicably persisted with annual fluctuations in the groundwater level even when the fluctuations were similar to those in previous years. We attribute this persistent land subsidence to secondary compression effects that accumulated even during the period of groundwater recovery. We developed a mechanistic model for the two sites and demonstrated its accuracy to forecast future land subsidence over several seasonal fluctuations of groundwater elevation.

Speaker



Ronaldo Borja

Professor | Stanford University

ID 106: Dual-Skeleton Effective Stress Modeling for Frozen Soils and Artificial Ground Freezing

5:40 PM – 6:00 PM

Author(s): Yingxiao Liu, Rowan University; WaiChing Sun, Columbia University; Ronaldo Borja, Stanford University

Freezing and thawing of soils involve coupled thermo-hydro-mechanical processes, pronounced rate dependence, and evolving interactions among soil grains, pore water, and ice. These mechanisms govern the deformation and strength evolution of soils and thus determine their long-term stability in both natural cold-region environments and engineered freezing applications such as artificial ground freezing (AGF). Despite significant progress, reliably predicting time-dependent freeze heave and thaw settlement remains challenging because existing models often capture phase change but do not fully represent the evolving load-transfer mechanisms among the constituent phases.

We present a unified computational framework based on a generalized effective stress theory that explicitly accounts for the transition of the ice phase from fluid-like crystals suspended in pore water to solid-like inclusions forming part of the load-bearing skeleton. This transition is modeled through a dual-skeleton formulation that enables a smooth shift from an unsaturated-flow regime to a fully frozen composite regime. By incorporating the rate-dependent mechanical behavior and creep of ice, the framework captures both short-term freezing dynamics and long-term deformation during sustained freezing.

The proposed model is implemented within a fully coupled finite element formulation and validated against laboratory-scale freeze-thaw experiments and a field-scale AGF tunneling project involving multi-stage freezing and excavation. Numerical simulations accurately reproduce the evolution of freezing fronts, surface heave, and time-dependent deformation observed in practice, and are further used to evaluate alternative freezing strategies. These results demonstrate the strong potential of the proposed framework as a predictive and design-oriented tool for AGF and other cold-region geotechnical applications.

Speaker



Yingxiao Liu

Assistant Professor | Rowan University

EMI Younger Member Town Hall

6:05 PM – 6:45 PM | Location: CHEM 140

Engineering mechanics analysis in action at CU Boulder

6:05 PM – 7:00 PM | Location: UMC - Glenn Miller Ballroom

Old Main and Hale Science are two of the oldest buildings on the CU Boulder campus (built in 1876 and 1894, respectively). A 2019 exterior condition assessment, conducted by the local Boulder office of national engineering firm Simpson Gumpertz & Heger, determined that both buildings required significant exterior masonry restoration. As a result of both analyses, Old Main recently received a full exterior restoration and Hale Science is in the process of reconstructing the grand entry stair while the building above is temporarily shored.

To see these restorations in action, attend a tour of both buildings, led by Peter Babaian (Senior Principal Engineer at Simpson Gumpertz & Heger) and Chris Sachs (CU Boulder Assistant Dean for Operations, Facilities, and Safety) on June 3rd at 6pm, departing from the University Memorial Center. Due to space constraints on the active construction site at Hale Science, this tour is limited to 30 people and close-toed shoes are required.

For additional details on each analysis and recommendations resulting from each, attend their associated conference presentation during the Heritage Structures mini-symposium (MS 062).

CU Boulder Center for Infrastructure, Energy, and Space Testing (CIEST) tour

6:05 PM – 7:00 PM | Location: UMC - Glenn Miller Ballroom

CIEST provides lab, pilot, and large-scale experiments using geotechnical centrifuges, structural dynamics, and material testing of metals, composites, and concrete. Each test is customized to meet the needs of each user under controlled environments. CIEST Projects are designed to demonstrate bold ideas into engineering solutions in all scales from small to large so that laboratory innovations find a systematic way to progress. This approach brings researchers, students, and industry experts together to test hypotheses and discover new technologies.

Thursday, June 04, 2026

Breakfast

7:00 AM – 8:00 AM

Buffet-style breakfast

7:00 AM – 8:00 AM

Light breakfast

7:30 AM – 8:00 AM

Light breakfast will be served until 9am. Foods and drinks are allowed in the Ballroom.

Registration

7:30 AM – 6:00 PM | Location: UMC - Aspen Rooms

Keynote: Agentic Scientific Machine Learning

8:00 AM – 9:00 AM | Location: UMC - Glenn Miller Ballroom

Agentic Scientific Machine Learning

George Em Karniadakis, Ph.D.

The Charles Pitts Robinson and John Palmer Barstow Professor of Applied Mathematics

Brown University

Abstract: Scientific Machine Learning (SciML) integrates data-driven inference with physical modeling to solve complex problems in science and engineering. However, the design of SciML architectures, loss formulations, and training strategies remains an expert-driven research process, requiring extensive experimentation and problem-specific insights. We introduce AgenticSciML, a collaborative multi-agent system in which over 10 specialized AI agents collaborate to propose, critique, and refine SciML solutions through structured reasoning and iterative evolution. The framework integrates structured debate, retrieval-augmented method memory, and ensemble-guided evolutionary search, enabling the agents to generate and assess new hypotheses about architectures and optimization procedures. Across physics-informed learning and operator learning tasks, the framework discovers solution methods that outperform single-agent and human-designed baselines by up to four orders of magnitude in error reduction. The agents produce novel strategies -- including adaptive mixture-of-expert architectures, decomposition-based PINNs, and physics-informed operator learning models -- that do not appear explicitly in the curated knowledge base. These results show that collaborative reasoning among AI agents can yield emergent methodological innovation, suggesting a path toward scalable, transparent, and autonomous discovery in scientific computing.

Biosketch: George Karniadakis is from Crete. He is an elected member of the National Academy of Engineering, National Academy of Arts and Sciences, and a Vannevar Bush Faculty Fellow. He received his S.M. and Ph.D. from Massachusetts Institute of Technology (1984/87). He was appointed Lecturer in the Department of Mechanical Engineering at MIT and subsequently he joined the Center for Turbulence Research at Stanford / Nasa Ames. He joined Princeton University as Assistant Professor in the Department of Mechanical and Aerospace Engineering and as Associate Faculty in the Program of Applied and Computational Mathematics. He was a Visiting Professor at Caltech in 1993 in the Aeronautics Department and joined Brown University as Associate Professor of Applied Mathematics in the Center for Fluid Mechanics in 1994. After becoming a full professor in 1996, he continued to be a Visiting Professor and Senior Lecturer of Ocean/Mechanical Engineering at MIT. He is an AAAS Fellow (2018-), Fellow of the Society for Industrial and Applied Mathematics (SIAM, 2010-), Fellow of the American Physical Society (APS, 2004-), Fellow of the American Society of Mechanical Engineers (ASME, 2003-) and Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA, 2006-). He received the William Benter Prize (2026), SES G.I. Taylor medal (2014), the SIAM/ACM Prize on Computational Science & Engineering (2021), the Alexander von Humboldt award in 2017, the SIAM Ralf E Kleinman award (2015), the J. Tinsley Oden Medal (2013), and the CFD award (2007) by the US Association in Computational Mechanics. His h-index is 159 (highest in Applied Mathematics) and he has been cited over 155,000 times.

Speaker



George Em Karniadakis

Professor | Brown University

Moderators



Mija Hubler

Associate Professor | University of Colorado Boulder

Coffee Break

9:00 AM – 9:30 AM | Location: UMC - Aspen Rooms & UMC - 235

MS 015: Digital and sensing technologies for smart monitoring of infrastructure and buildings

9:30 AM – 11:30 AM | Location: HUMN 250

Chair(s): Bryan G. Pantoja Rosero; Shenghan Zhang; Salvatore Salamone; Matthew DeJong

Moderatorss



Bryan Pantoja Rosero

Prof. | Nanyang Technological University, Singapore



Shenghan Zhang

Prof. | Hong Kong University of Science and Technology (HKUST)

ID 182: Monitoring Method for a Spread Footing Foundation Using Embedded Crossed Long-Gauge Sensors

9:30 AM – 9:50 AM

Author(s): Yitian Liang, Princeton University; Branko Glisic, Princeton University

Spread footing foundations are critical structural components responsible for transferring loads from superstructures to the supporting soil. Their performance directly affects structural safety and long-term serviceability. However, spread footing foundations are rarely monitored due to their geometry and inherently high stiffness, which result in complex strain distribution under loading. Furthermore, the traditional technique of attaching strain sensors to structural surfaces is not always applicable to underground foundations.

This research presents a study on an efficient monitoring method for performance monitoring of a reinforced concrete spread footing foundation using embedded long-gauge fiber Bragg grating (FBG) sensors arranged in crossed topologies. The monitoring method was explored and verified during the on-site assembly of a precast parking garage, where the sequential addition of superstructure components provided incremental and well-defined loading conditions. The long-gauge FBG sensors were embedded within the footing to continuously capture strain and temperature data throughout construction. The crossed sensor topology was adopted to enhance sensitivity to shear-related response within the footing. To support interpretation of the measured data, analytical and numerical modeling approaches were employed to relate construction-stage loading to the observed strain response. Finite element modeling was used to simulate the structural system under staged construction loads and to examine the spatial distribution of strain within the foundation, exploring the influence of sensor locations on their response.

The results demonstrate that the embedded crossed long-gauge sensors, with sensor locations selected to be sensitive to shear-related response, effectively captured strain responses within and overall structural behavior of the spread footing during construction-stage loading. The measured strain evolution exhibits consistent trends corresponding to the sequential assembly of the superstructure, indicating stable load transfer and predictable foundation behavior under incremental loading. Finite element simulations were used to validate the measured strain response and to aid in understanding the influence of sensor topology and location on measurement sensitivity. Overall, this study provides experimental evidence of the construction-stage response of a spread footing foundation and demonstrates the value of the proposed monitoring method for capturing behavior in stiff foundation elements. The findings contribute to improved understanding of foundation load transfer and highlight the importance of sensor placement informed by shear sensitivity, which can enhance the performance and design of monitoring methods for foundational elements and advance predictive maintenance strategies.

Speaker



Yitian Liang

Ph.D. Candidate | Princeton University

ID 279: Understanding Measurement Noise and Error Propagation in Backscatter-based Radio Frequency Sensing for Spatial Displacement Structural Health Monitoring

9:50 AM – 10:10 AM

Author(s): Kent Eng, Princeton University; Yuanqing Song, Stony Brook University; Yang Xie, Stony Brook University; Zygmunt Haas, Cornell University and University of Texas at Dallas; Samir Das, Stony Brook University; Petar Djurić, Stony Brook University; Milutin Stanačević, Stony Brook University; Branko Glisic, Princeton University

Embedded backscatter-based batteryless radio frequency (RF) sensors (BBRS) have recently emerged as a promising solution for long-term three-dimensional spatial structural health monitoring based on RF channel phase measurements. Such systems can potentially be deployed in various infrastructure monitoring applications, including pavement subsurface, concrete bridges, and levees. The BBRS system leverages backscatter techniques to estimate the displacement changes between sensors based on the sensors' channel phase. While recent research has focused on hardware development and capability demonstration, the characterization of channel phase measurement noise and its impact on downstream computations remains insufficiently understood. In particular, the measurements of the channel phase contain patterned noise that degrades the accuracy of individual localization and propagates through the system, ultimately affecting strain estimation. Therefore, it is of interest to estimate and quantify the measurement noise and understand how error propagation influences system computation, so as to effectively calibrate and minimize the effect of systematic noise.

This presentation introduces a principled error propagation model of the BBRS systems and investigates its effects on sensor localization and strain computation. The noise models are calibrated using experimental data, and the error-propagation models are validated through displacement experiments with multiple BBRS units. The primary challenges of this research include identifying the noise patterns in channel phase under various settings and establishing an error propagation model for the computation of sensor localization and strain computation in the BBRS system.

The modelling results demonstrate the effects of error propagation on the BBRS system and are validated by experimental data under different configurations. Our framework provides a better understanding of the system performance, noise level, and calibration method. By further investigating denoising and calibration methodologies using the error propagation model, the accuracy and reliability of BBRS can be significantly improved, thus increasing the readiness of BBRS deployment in real-world scenarios.

Speaker



Kent Eng

PhD Candidate | Princeton University

ID 388: Embedded Self-Sensing Cementitious Composite Layers in 3D Printed Functional Materials for Structural Health Monitoring

10:10 AM – 10:30 AM

Author(s): Moneef Mohamed Elohaid Musa, Iowa State University; Han Liu, Iowa State University; Israel Nilton Lopes Sousa, University of Perugia; Pushp Raj Poudel, Iowa State University; Antonella D'Alessandro, University of Perugia; Filippo Ubertini, University of Perugia; Shelby Doyle, Iowa State University; Simon Laflamme, Iowa State University

Additive manufacturing of cementitious materials offers significant opportunities for automated construction and the development of advanced structural functionalities. However, the reliability of 3D-printed concrete components remains strongly affected by uncertainties introduced during the printing process, particularly those related to layer-wise deformations, interlayer bonding, and extruded material's properties. These phenomena are primarily governed by key printing parameters—including printing speed, extrusion velocity, and nozzle height, which together control stress development and deformation during material deposition. Building on recent advances in self-sensing 3D-printed cementitious composites for real-time process monitoring, this study integrates conductive cementitious materials as embedded sensing layers within printed elements. These sensing layers consist of cement paste functionalized by incorporating graphite powder and carbon microfibers at a level that boosts the material's piezoresistive properties, thus promoting strain sensing capabilities by monitoring changes in electrical resistance. The experimental results show that the embedded self-sensing layers are capable of monitoring bending-induced strain post-fabrication, and capable of tracking the printing process as well as certain defects during fabrication. These findings support the feasibility of embedding self-sensing cementitious composited within a 3D printed element to enable structural health monitoring tasks and empower the digital construction workflows.

Speaker



Moneef Mohamed Elohaid Musa

Iowa State University

ID 447: Vision-driven finite element modeling of earthquake-damaged masonry elements

10:30 AM – 10:50 AM

Author(s): Bryan German Pantoja-Rosero, Nanyang Technological University; Qianqing Wang, École polytechnique fédérale de Lausanne; Leon Lobo, Universidade de São Paulo; Raul Durand, Universidade de Brasília, Brasília

This study presents an automated, vision-based framework for the numerical analysis of masonry structures affected by seismic events, with particular emphasis on rapid post-earthquake assessment. Leveraging advances in computer vision and image-based reconstruction, the proposed methodology integrates photogrammetry modeling and semantic damage segmentation to generate computationally ready finite element representations directly from images. Structural damage identified from visual data is incorporated into the numerical model through a damage-informed constitutive formulation, enabling the spatial updating of element-level mechanical properties in accordance with observed deterioration. The approach is validated through laboratory tests on stone masonry walls and subsequently applied to a masonry building damaged during an earthquake. In addition to enabling efficient model generation, the framework provides enhanced interpretability of damage distributions, thereby supporting future research in structural diagnosis and integrity assessment. Ongoing and future work will focus on improving damage extraction accuracy and extending the methodology to a broader range of structural systems.

Speaker



Bryan Pantoja Rosero

Prof. | Nanyang Technological University, Singapore

ID 596: Stevenson Creek Experimental Dam: Centenary of and Advancements in Modern Strain- and Displacement-Based Monitoring of Civil Structures

10:50 AM – 11:10 AM

Author(s): Branko Glisic, Princeton University

Electrification in the USA at the turn of 20th century necessitated construction of dams for hydropower plants. Concrete, as increasingly used construction material at that time, promised departure in dam design from well-understood but material-intensive gravity dams towards much lighter and significantly less material-intensive, arch and multiple arch dams. However, shell-like arch and multiple arch dams had unsafe appearance, their design principles were not developed yet, and structural behaviors were not fully understood. To address these challenges, Swiss American engineer, Fred A. Noezli, proposed building an experimental arch dam, instrumenting it with large number of strain, displacement, and temperature sensors, and performing series of tests that would lead to enlarged understanding on the dam's safety and structural behavior, and to development of its design principles. His proposal was accepted by Engineering Foundation and Southern California Edison Company, and as a result Stevenson Creek Experimental Dam was built in 1924-1925, near the city of Fresno, California. To assess structural behavior of the dam during the tests, six types of sensors were installed in a spatially dense arrangement, with aim of measuring deformation-related parameters, such as strain, curvature, and displacement. In addition, temperature was measured too. Four types of sensors were installed on the surface of the dam and they were operated manually. However, the use of concrete as a relatively new construction material necessitated the use of embedded strain sensors, while large dimensions of the dam inspired the use of remotely operated sensors. Consequently, two new types of sensors were pioneered and deployed: embeddable resistive strain sensors consisting of stacks of carbon discs, developed by Barton McCullom and O.S. Peters, and resistive deflection sensors developed by Col. George S. Binkley. Instrumentation of Stevenson Creek Experimental Dam led to several paradigm changes in assessing structural behavior: to the author's best knowledge the use of remotely operated sensors in the project was the first such application in the USA, and it represents the first application of modern monitoring technique in the country; it generated the first large dataset collected from a real-sized structure and resulted in one of the first physics-based data analysis technique, and in the first examples of onsite system identification and damage detection. The first centenary of this visionary project stimulates reflection on past achievements and the future developments on strain- and displacement-based monitoring of civil structures, which are presented in the context of the Stevenson Creek Experimental Dam project.

Speaker



Branko Glisic

Professor and Chair of CEE | Princeton University

ID 756: Strain Field Reconstruction and Crack Quantification Using Distributed Fiber Optic Sensing

11:10 AM – 11:30 AM

Author(s): Xuanyi Lu, The Hong Kong University of Science and Technology; Sudao He, The Hong Kong University of Science and Technology; Shenghan Zhang, The Hong Kong University of Science and Technology

Distributed fiber optic sensing (DFOS) enables continuous measurement of strain distributions along sensing fibers, offering a promising approach for strain monitoring and crack quantification in structures. Nevertheless, two key challenges hinder its application: (1) strain transfer effects induced by the protective coatings and nonlinear behaviors of optical fibers, which cause discrepancies between the measured and real structural strain; and (2) the complexity of crack orientations and the overlapping of strain peaks generated by multiple cracks, which makes it difficult to accurately infer detailed crack information. To address these issues, this study proposes an integrated analytical and deep learning-based framework. First, considering the influence of cable structural parameters and strain field types, a deep learning method was developed to reconstruct the real strain field of the host matrix from the fiber measurements. Second, for single-crack scenarios, analytical algorithms based on strain distribution shapes and fiber elongation were established to identify crack orientations and correct crack width calculations. Finally, for multiple-crack scenarios with overlapping strain peaks, a physics-constrained deep learning model was constructed to simultaneously predict crack locations and widths. This study substantially enhances the reliability and interpretability of DFOS and broadens its applications in structural health monitoring.

Speaker



Xuanyi Lu

PhD Candidate | The Hong Kong University of Science and Technology

MS 003: Robotics and automation for SHM and construction management

9:30 AM – 11:30 AM | Location: HUMN 135

Chair(s): Yang Wang; SangHyun Lee; Genda Chen; YoungJin Cha

Moderators



Youngjin Cha

Professor, F.ASCE, HCR | University of Manitoba

ID 48: Context-Aware Human-Robot Interaction in Construction

9:30 AM – 9:50 AM

Author(s): Xin Wang, Zachry Department of Civil and Environmental Engineering, Texas A&M University

With the evolution of Industry 4.0, construction robotics is emerging as a driven force for transforming traditional and potentially hazardous construction processes into more automated and safer ones. However, robots and autonomous machines have not been widely adopted on construction sites. There are various reasons contributing to the low adoption of robots in construction including operational and personnel barriers. An intuitive and accurate human-robot interface can help contribute to resolving the above barriers. It could allow the robotics systems to conduct multiple tasks guided by construction workers. Also, such interface helps to build a safe environment for worker-robot collaboration.

In this study, a context-aware interface is proposed to support worker-robot collaboration on construction sites. It consists of three components: recognition building, object-enhanced interaction and machine-aware collaboration. In the first component recognition building, a novel vision-based method and a novel wearable sensors-based method are developed to recognize hand gestures performed by the workers. Further, a comparison study is conducted to analyze their pros and cons. In the second component object-enhanced interaction, a novel object-aware method is proposed to improve the interaction efficiency for human-robot collaboration in construction, integrating first-person vision and gesture recognition. The proposed method models the user's gaze using an attention module to concentrate on the important spatiotemporal regions of first-person video for object context extraction. In the third component machine-aware collaboration, a novel machine-aware hand gesture recognition method is developed as a human-robot interface for use on construction sites having multiple types of machines. The developed method relies on an eye tracker to visually detect and track construction machines in the first-person view and indicate which machine the user intends to interact with.

The above methods have been evaluated and tested by experiments across various construction sites. The results of these evaluations have shown that the proposed methods could effectively capture and interpret worker intents with context awareness, thereby enhancing human-robot collaboration on construction sites. The anticipated contributions of these methods include enhancing interaction efficiency with construction robots, reducing onsite safety concerns, optimizing the design and implementation of construction robots, and fostering the adoption of robots in construction, etc.

Speaker



Xin Wang

Assistant Professor | Texas A&M University

ID 370: A Photoelasticity-Based Robotic Tactile Sensor: Advances in Stress Sensing for Human-like Touch

9:50 AM – 10:10 AM

Author(s): Zijie Xu, Stony Brook University; Rakibul Islam Prince, Purdue University; Jiabin Liu, Michigan State University; Shaoting Lin, Michigan State University; Yu She, Purdue University; Wei Li, Stony Brook University

Human tactile sensing relies on a dense and highly organized network of mechanoreceptors embedded within the skin, enabling humans to accurately perceive contact stress and the mechanical properties of interacting objects. Inspired by the dexterity of human hands, tactile sensing is crucial for robotic manipulations. However, existing vision-based tactile sensors primarily perceive objects by visualizing touch-induced deformation but lack the ability to interpret contact stress. This limitation makes it challenging to accurately perceive and manipulate soft or fragile materials, creating a gap between robotic tactile sensing and human tactile perception.

Photoelasticity is a powerful experimental technique to visualize stresses by converting stress-induced birefringence in some transparent polymers into images, providing a unique opportunity for contact stress visualization and robotic tactile perception. However, in a conventional photoelastic testing setup, particularly transmissive photoelasticity, a complex imaging setup composed of a light source, filters, and cameras aligned in a darkroom is used to visualize and quantify stresses, making it difficult to integrate into robotic tactile sensing.

Here, we design a photoelasticity-based tactile sensor that can operate outside a darkroom, with a form factor comparable to that of human fingers. Our design relies on reflective photoelasticity to reduce the size of the imaging setup and enable real-time visualization of contact stresses. To develop a theory to interpret the resulting images as contact stresses, we first developed a numerical model to simulate them based on the known 3D stress distribution in our sensor—the forward problem. Guided by 3D photoelasticity theory, our model predicts the resulting image for many contact scenarios between our sensor and everyday objects, and matches very well with our sensor's results. This physics-based forward modeling approach establishes a direct link between contact-induced stress fields and the corresponding photoelastic images, thereby providing a foundation for a physics-informed machine learning framework to infer the mechanical and physical properties of objects from photoelastic images.

Speaker



Zijie Xu

PhD student | Stonybrook University

ID 378: Developing Approaches for Robotic Excavation of Nuclear Waste

10:10 AM – 10:30 AM

Author(s): Evelyn Fernandez, Los Alamos National Laboratory; Anthony Starleaf, Los Alamos National Laboratory; Thanatat Thanaravisara, Los Alamos National Laboratory; Moises Mello da Silva, Los Alamos National Laboratory; Andre Green, Los Alamos National Laboratory; David Mascarenas, Los Alamos National Laboratory

The Hanford Tanks are underground storage tanks at Hanford Site in Washington State that contain millions of gallons of radioactive waste created during the Cold War plutonium production era. Some of these tanks are leaking, posing a potential hazard to the surrounding environment. Dry retrieval has been identified as an alternative to current sluicing methods for the retrieval and translation of this waste with the hope of increasing efficiency and substantially reducing the amount of water currently required. The vision for dry retrieval involves the use of robotic and mining technology to mobilize, excavate and exfiltrate the waste out of the tank. The waste itself comes in three forms: liquid, saltcake and sludge. The sludge is characterized as being of peanut butter-like consistency. Access to the tanks is currently assumed to be limited to 42" diameter or smaller, holes. These factors and constraints shape how technical strategies for Hanford dry retrieval are developed. The team is simultaneously working on different technologies that will work together to ensure continuity in operations in this complex environment. Currently it is anticipated that planning for dry retrieval will make heavy use of simulations that couple rigid body dynamics, with granular mechanics, cable mechanics and light ray-tracing for photorealism.

The development of these simulators is underway. A Brokk 70 demolition robot is being deployed for its size and ability to break up the material for retrieval. In addition, screw-propelled robotic vehicles are being constructed for their ability to navigate mud-like terrains expected to be found in the tanks. Both are equipped with excavator buckets to retrieve the waste thus a new bucket design is underway to ensure the waste is properly extruded during discharge, addressing problems that arise with the waste's adhesion properties. Furthermore, humanoid robotics is being explored with a new robotic arm design to perform operational tasks such as setups, maintenance/repair, recovery and other tasks requiring dexterity. To evaluate the equipment and operations, simulations are being produced for time and motion studies. Among these are terramechanic models to test and simulate individual grain behavior and complex interparticle interactions, these can be used to estimate various parameters like how much waste can be piled at a central collection point. The benefit of a successful deployment of this dry retrieval system goes far beyond the Hanford clean up mission. Critical mineral extraction mining in red mud plays a significant role in the future industrial and technological advancements. Its pronounced alkalinity and abrasive nature is similar to the waste found inside the Hanford tanks. The technologies for retrieve, translate, and exfiltrate the waste withing these tanks can be directly translated to this emerging field, mitigating the current lack of effective technologies for the processing of this hazardous material.

Speaker



Evelyn Fernandez

Graduate Research Assistant | Los Alamos National Laboratory

ID 1039: Real-time Adaptive Control for Robotic Concrete 3D Printing

10:30 AM – 10:50 AM

Author(s): Muhammad Arslan, University of Houston; Vedhus Hoskere, University of Houston

Robotic concrete 3D printing constructs structures layer by layer by using a 3D printing system attached to a robot. Layer width and height depend on material rheology and printer parameters including nozzle travel speed and nozzle offset. A consistent and appropriate layer width and height is essential for buildability, structural integrity, and geometrical accuracy. Different concrete mixes have different rheology and finding suitable initial printing parameters is a challenge. Current industrial practice mainly relies on manual trials which result in material loss and time consumption. Material rheological properties vary during printing due to changes in moisture in environment and hydration or a new mix is introduced during printing. Therefore, conventional 3D printing systems need to be stopped and do the parameter tuning again manually resulting in idle time and material loss. To solve these two problems, this study proposes a real-time adaptive framework combining Reinforcement Learning (RL) and Incremental Extreme Learning Machine (IELM) via Model Predictive Control (MPC). Layer width and height are measured in real time and fed to main control to adjust the nozzle speed and offset to get to appropriate initial printing parameters and after this also maintain layer geometry within the desired range. A systematic experimental approach has been followed by comparing four sets of control configurations, constant speed and constant offset, RL+IELM+MPC, IELM only, and RL only to assess the performance of these control methods in reaching the appropriate initial parameter setting and under rheological changes maintaining consistent layer width and height by comparing it to benchmark (constant speed and offset). RL+IELM+MPC reduced average width error by 94% and average height error by 95% and it outperforms both RL only and IELM only. This study demonstrates that proposed framework enables autonomous initial parameter identification, eliminating manual tuning and maintaining consistent printing under variation in material behavior.

Speaker



Muhammad Arslan

PhD Student | University of Houston

ID 216: Agentic Large Language Models for Automated Structural Analysis of 2D Frames

10:50 AM – 11:10 AM

Author(s): Ziheng Geng, University of Miami; Minghui Cheng, University of Miami

Large language models (LLMs) have emerged as powerful enablers for agentic systems, demonstrating significant potential to transform scientific and industrial workflows. However, their application within structural engineering remains largely unexplored, particularly in automating labor-intensive structural analysis workflows. To address this gap, this study proposes an LLM-based multi-agent system for automated finite element modeling of 2D frame structures. The proposed system decomposes structural modeling into a sequence of subtasks, each handled by a specialized agent powered by a lightweight Llama-3.3 70B Instruct model. Specifically, the Problem Analysis Agent extracts geometry, boundary, and material parameters from natural language inputs. The Geometry Agent then constructs node coordinates and element connectivity using expert-defined rules and outputs the results in a JSON format. These structured representations are translated into executable OpenSeesPy code by a Translation Agent and subsequently verified by a Model Validation Agent to detect and correct modeling inconsistencies. Finally, a Load Agent appends load analysis commands to the existing code, yielding a complete and executable script. Evaluation on 20 benchmark problems demonstrates that the system achieves over 80% accuracy across 10 repeated trials, substantially outperforming state-of-the-art general-purpose LLMs, including GPT-4o and Gemini 2.5 Pro.

Speaker



Minghui Cheng

Assistant Professor | University of Miami

ID 988: Lab-to-Field Integrated Deep Learning for UAV-Based Crack Detection in Bridge Structures

11:10 AM – 11:30 AM

Author(s): Nazila Jamshidighadikolaei, Louisiana Tech University; Hadi Salehi, Louisiana Tech University

Recent advances in unmanned aerial vehicles (UAVs) and computer vision have enabled new opportunities for automated structural health monitoring (SHM) of bridges. Nevertheless, most existing vision-based SHM approaches depend on static field imagery or synthetic datasets, limiting their ability to combine information related to damage progression and to generalize robustly to real-world inspection conditions. This study presents a hybrid SHM framework that integrates UAV-based visual inspection with a deep learning model trained on both laboratory and field imagery. Laboratory tests on reinforced concrete beams subjected to progressive shear loading provide temporally ordered crack images that encode damage evolution, while UAV-captured images from in-service bridges present real-world visual variability associated with operational environments. The proposed framework merges a convolutional neural network architecture (CNN) with a long short-term memory (LSTM) network, where the LSTM is employed as a temporal regularizer during training to enable progression-aware feature learning. To evaluate the contribution of temporal supervision, the CNN-LSTM model is benchmarked against purely spatial baselines. Results demonstrate that the proposed deep learning model consistently outperforms the baseline models across laboratory and field datasets, achieving higher accuracy and improved robustness under varying environmental conditions. By leveraging laboratory-informed temporal supervision while retaining single-frame inference capability for field imagery, the proposed lab-to-field integrated framework offers a scalable and practical solution for UAV-enabled bridge monitoring, even in scenarios where high-frequency temporal data are unavailable.

Speaker



Hadi Salehi

Assistant Professor | Louisiana Tech University

MS 006: Digital twins for SHM and infrastructure management

9:30 AM – 11:30 AM | Location: HUMN 125

Chair(s): David Lattanzi; Youngjin Cha; Mani Golparvar Fard

Moderators



David Lattanzi

Professor | George Mason University

ID 43: Integrating thermal point clouds, object detection, and virtual reality for building envelope assessments

9:30 AM – 9:50 AM

Author(s): Gaurav Chandrakant Modak, University of Massachusetts Lowell; Max Cohn, University of Massachusetts Lowell; Jordan Allspaw, University of Massachusetts Lowell; Holly Yanco, University of Massachusetts Lowell; Christopher Niezrecki, University of Massachusetts Lowell; Alessandro Sabato, University of Massachusetts Lowell

Accurately characterizing the thermal performance of building envelopes is essential for improving energy efficiency and supporting data-driven infrastructure management. This work presents an integrated framework that leverages three-dimensional (3D) point clouds, deep-learning-based object detection, and immersive virtual reality (VR) to support next-generation digital twins for condition monitoring of buildings. Thermal imagery collected from aerial platforms is converted into thermal point clouds that capture both geometric and temperature distributions across the building envelope. A tailored object detection pipeline, trained to identify façade components such as windows, doors, and insulation discontinuities, is fused with the thermal point cloud to segment envelope features and automatically localize potential thermal anomalies. To enhance interpretability and support practitioners' decision-making, the fused deep-learning thermal dataset is embedded in an interactive VR environment that enables inspectors to examine defects at their actual scale, visualize temperature gradients, and interrogate metadata within an immersive digital twin. The proposed system not only improves defect detectability but also reduces inspection time and enhances accessibility to complex or hazardous areas. A case study of buildings at the University of Massachusetts Lowell demonstrates that the framework can identify insulation voids and air-leakage points with high spatial precision, while providing an intuitive platform for scenario exploration and retrofit planning. The results illustrate the potential of integrating thermal point clouds, AI-driven object detection, and VR interfaces to advance digital twins for condition monitoring and energy management of critical structures.

Speaker



Alessandro Sabato

Dr. | University of Massachusetts Lowell

ID 99: GateBlend LSTM Models for Predicting Nonlinear Structural Responses in Digital Twin Implementation

9:50 AM – 10:10 AM

Author(s): Baiping Dong, Tongji University; Ahsan Shahbaz, Tongji University; Theodoros Karavasilis, University of Patras

This study develops and evaluates advanced deep learning models for predicting nonlinear seismic responses with direct applications to Digital Twin (DT) frameworks. Four variants of Long Short-Term Memory (LSTM) models are explored. The physics-guided GateBlend architecture incorporates a drift-correction mechanism that combines pointwise and integrated displacement paths through a cross-parameter learnable gating mechanism, enhancing both stability and long-term prediction accuracy. The models are trained and validated using both digital-domain finite element simulations and physical-domain experimental datasets from three structures, evaluated under separate and combined design basis earthquake and maximum considered earthquake scenarios. The results demonstrate that the GateBlend models outperform baseline LSTM models in terms of structural displacement response accuracy, while maintaining strong predictions for structural velocity and acceleration responses. Fine-tuned GB-LSTM models show robustness across structures and provide stable predictions for all displacement, velocity, and acceleration responses, establishing these models as reliable surrogate predictors for real-time monitoring and seismic risk assessment in high-fidelity DT models. Overall, the study highlights the superior effectiveness of GateBlend LSTM models over baseline LSTM models for DT-enabled nonlinear structural response prediction.

Speaker



Baiping Dong

Dr. | Tongji University

ID 289: Development of a Multi-View-Based Verticality Measurement Method for PC Segment Vertical Shafts

10:10 AM – 10:30 AM

Author(s): kyoung min kim, Department of Global Smart City Engineering, Sungkyunkwan University, Suwon, Republic of Korea; Seung soo Lee, Department of Global Smart City Engineering, Sungkyunkwan University, Suwon, Republic of Korea; Seung Hee Kwon, Professor, Dept. of Civil and Environmental Engineering, Myongji Univ., Yongin, Republic of Korea; Eom sik Ko, CEO, Neo City Co., Ltd., Seoul, Republic of Korea; Seunghee Park, School of Civil, Architectural Engineering & Landscape Architecture, Sungkyunkwan University, Suwon, Republic of Korea

This study proposes a multi-view-based verticality measurement technique to quantitatively monitor the construction verticality of precast concrete (PC) segment vertical shafts, a critical process in deep underground infrastructure projects. Vertical shafts are essential structures for evacuation, ventilation, and fire emergency response; therefore, tilt occurring during construction can lead to accumulated construction errors and increased maintenance risks. In particular, although PC segment methods are prone to verticality deformation due to self-weight effects during excavation and sinking operations, field-applicable low-cost, non-contact, high-frequency measurement technologies remain limited, and conventional methods suffer from limitations such as work interference, low measurement frequency, and insufficient quantification.

To address these issues, this study presents a multi-view verticality measurement procedure based on acquiring videos from multiple viewpoints. The proposed method automatically defines a region of interest corresponding to the inner shaft wall and extracts stable tracking points across frames. It then reconstructs a 3D point cloud by fusing 3D reconstruction results derived from multi-view geometry and monocular depth estimation outputs. Using the reconstructed point cloud, the shaft axis is estimated via RANSAC and PCA. Finally, verticality is quantified by computing the deviation between the estimated axis and the gravity direction, reported in both angular units and mm/m.

Overall, the workflow integrates video acquisition, automated ROI delineation, point tracking, and hybrid depth-aware reconstruction into a single measurement chain that is compatible with practical construction environments. By combining multi-view geometry with monocular depth cues, the approach strengthens 3D consistency while preserving robustness when viewpoints vary. The subsequent RANSAC-PCA axis fitting provides a repeatable estimate of the shaft centerline, and the final angle and mm/m outputs translate directly into familiar quality-control metrics. In this way, the method supports continuous interpretation of verticality trends and facilitates timely interventions. It also streamlines visualization of results, helping engineers communicate findings during site reviews.

The proposed technique is expected to (1) enable high-density, non-contact verticality monitoring without target markers, thereby reducing installation and operational costs; (2) mitigate quality deterioration and rework risks by early detection of abnormal verticality during construction; and (3) improve the speed and objectivity of on-site decision-making through time-series analysis and visualization of measurement results.

Speaker



Kyoungmin Kim

Sungkyunkwan University

ID 291: LLM-Based Interactive Decision Support Framework for Bridge Maintenance

10:30 AM – 10:50 AM

Author(s): Mingeon Cho, Sungkyunkwan University; Ki Hwan Kim, Korea Expressway Corporation Research Institute; Inhi Kim, Korea Advanced Institute of Science and Technology; Seunghee Park, Sungkyunkwan University

This study proposes an interactive decision support framework for bridge maintenance based on Large Language Model (LLM) to enhance safety assurance and improve the efficiency and consistency of maintenance-related decisions for aging bridges. Conventional bridge maintenance practices rely heavily on expert judgment due to large volumes of heterogeneous data, unstructured inspection and diagnostic reports, and the complexity of interpreting maintenance standards and guidelines. This reliance increases time and cost burdens and leads to variability in decision outcomes. To address these challenges, an LLM-based AI agent framework is developed to support integrated decision support for bridge maintenance.

Both structured and unstructured maintenance data were systematically reorganized to improve reliability and retrieval efficiency. Structured data were refined using hash-based bridge identifiers and data filtering, enabling consistent and rapid information retrieval. Unstructured data, including manuals and diagnostic reports, were standardized, preprocessed to reflect Korean language characteristics, and converted into a vector database to establish a semantic knowledge base for maintenance decision support.

To ensure response reliability and reduce hallucination, the framework adopts a Retrieval-Augmented Generation (RAG) architecture. The system integrates a multi-head RAG structure that separates retrieval and response generation according to query types, a hybrid retrieval approach combining semantic similarity and keyword-based search, and post-generation verification and re-ranking processes. A conversational user interface supports a continuous workflow encompassing bridge information retrieval, interpretation of standards and guidelines, damage image assessment, expansion joint distress diagnosis, and automated drafting of maintenance-related decision reports.

The framework was evaluated using 38 technical advisory reports. Initial agreement with expert judgments was 74%, which improved to 84% after re-verification of mismatched cases and further increased to 97% following prompt and reasoning logic refinement. Image-based damage classification accuracy similarly improved from 75% to 97% after prompt optimization. In a pilot application involving 50 components from 35 bridges, expansion joint distress assessments fully matched expert evaluations, while cause analysis and repair decision accuracy reached 80% and 84%, respectively. These results demonstrate the practical applicability of the proposed LLM-based framework as a reliable decision support tool for bridge maintenance decision-making.

Speaker



Mingeon Cho

SUNGKYUNKWAN UNIVERSITY

ID 379: Advances in 3D Reconstruction for Civil Engineering: From Structure-from-Motion to NeRF and Gaussian Splatting

10:50 AM – 11:10 AM

Author(s): Qasim Bin Saeed, University of Manitoba; YoungJin Cha, University of Manitoba

This study presents a comprehensive and systematic review of 3D reconstruction techniques for Structural Health Monitoring (SHM) and construction management, tracing their technological evolution from classical geometry-based methods to modern learning-driven neural rendering approaches. The review begins with traditional Structure-from-Motion (SfM) and Multi-View Stereo (MVS) techniques, which have long served as the foundation for photogrammetric reconstruction of civil infrastructure. These methods rely on handcrafted feature detection, camera pose estimation, and dense point cloud generation, and have been widely adopted due to their geometric interpretability and metric accuracy. However, their performance often degrades in large-scale, texture-poor, or repetitive structural environments, and they typically require extensive manual intervention and post-processing.

Building upon this foundation, the paper examines the gradual incorporation of computer vision, photogrammetry, and deep learning techniques that have improved robustness, automation, and reconstruction quality. The emergence of deep learning has enabled more reliable feature extraction, semantic understanding, and noise suppression, facilitating the transition from sparse geometric models to dense, photorealistic 3D representations. Within this context, the review places particular emphasis on recent neural rendering methods, including Neural Radiance Fields (NeRF) and Gaussian Splatting, which represent a paradigm shift from explicit surface reconstruction to implicit, view-consistent scene representations. These approaches have demonstrated unprecedented capabilities in capturing fine geometric details, complex material properties, and realistic lighting effects, making them highly attractive for infrastructure visualization and inspection.

The review further highlights the critical role of unmanned aerial vehicles (UAVs) in enabling scalable and automated data acquisition, especially for large, complex, and hard-to-access structures such as bridges, towers, and high-rise buildings. Advances in autonomous navigation, sensor fusion, and mission planning have significantly enhanced the quality and consistency of image data, supporting the creation of high-fidelity digital twins for continuous inspection, monitoring, and lifecycle management. The integration of 3D reconstruction with digital twin frameworks is discussed as a key enabler for transitioning SHM from periodic, manual inspections to continuous, data-driven assessment.

A critical evaluation of state-of-the-art reconstruction models is provided, comparing their strengths, limitations, computational demands, and suitability for deployment in real-world SHM scenarios, particularly in complex and remote environments. While geometry-based methods offer physical interpretability and metric reliability, learning-based approaches excel in visual realism, adaptability, and robustness to incomplete data. By establishing conceptual and methodological connections between these paradigms, the study outlines the ongoing transition toward real-time, immersive, and intelligent monitoring frameworks.

The findings indicate that although recent advances—especially NeRF and Gaussian Splatting—show significant promise for achieving high-fidelity and near-real-time reconstruction, substantial challenges remain. These include scalability to large infrastructures, robustness under varying environmental and illumination conditions, and seamless integration with SHM analytics such as damage detection, condition assessment, and predictive maintenance. Overall, this review aims to provide a unified understanding of the technological evolution of 3D reconstruction for SHM and construction management, while identifying key research gaps and future directions toward fully automated, intelligent, and resilient infrastructure management systems.

Speaker



Qasim Bin Saeed

Mr. | University of Manitoba

ID 710: Structure-preserving Operator Inference for Nonlinear Mechanical Systems: Foundations for Predictive Digital Twins

11:10 AM – 11:30 AM

Author(s): Harsh Sharma, Department of Mechanical Engineering, University of Wisconsin-Madison

Operator inference is a powerful approach for data-driven model reduction, where reduced-order models (ROMs) are learned directly from simulation or experimental data without requiring intrusive access to high-dimensional full-order models. However, standard data-driven ROMs for mechanical systems often neglect the underlying geometric structure, leading to energy drift and inaccurate long-time predictions. To overcome these challenges, we develop structure-preserving operator inference for data-driven model reduction of nonlinear mechanical systems. The proposed nonintrusive approach embeds the mechanics into the operator inference framework to develop a data-driven model reduction method that preserves the underlying Lagrangian structure. We present outer-loop applications ranging from dynamic shape control of soft robots via linear Lagrangian ROMs to learning nonlinear Lagrangian ROMs for backbone curve prediction in jointed structures. The numerical results demonstrate that the proposed approach yields generalizable data-driven ROMs that respect the conservation laws, capture the nonlinear characteristics reliably, and provide accurate long-time predictions outside the training data regime. Finally, we discuss the potential of such structure-preserving ROMs in the context of digital twins, where stability and predictive fidelity are critical for data-informed decision-making.

Speaker



Harsh Sharma

Assistant Professor | University of Wisconsin-Madison

MS 039: Architected Materials

9:30 AM – 11:30 AM | Location: HUMN 1B50

Chair(s): Yunlan (Emma) Zhang; David Restrepo; Josephine Carstensen; Nilesh Mankame; Pablo Zavattieri

Moderators



Nilesh Mankame

Staff Researcher | General Motors

ID 194: On the surface waves in truncated phononic crystals

9:30 AM – 9:50 AM

Author(s): Long Nguyen, University of Minnesota; Prasannakumar Salasiya, University of Minnesota; Bojan Guzina, University of Minnesota; Shixu Meng, University of Texas at Dallas

In this work, we investigate the in-plane surface Bloch (SB) waves in periodic elastic media. These waves propagate along the traction-free cut surface while exhibiting evanescent decay in the direction orthogonal to the cut plane. The medium is modeled as a truncated periodic structure with a rationally-oriented surface cut endowed with traction-free boundary conditions. To characterize such boundary layers, the Floquet–Bloch theorem is applied to the 2D Navier equations, leading to a formulation in terms of vector-valued Bloch wave states. This procedure results in a quadratic eigenvalue problem (QEP) defined over an effective unit cell of the truncated periodic medium, defined by the orientation of the (rational) cut. For a prescribed frequency and wavenumber component parallel to the surface cut, the featured QEP seeks the complex wavenumbers in the direction orthogonal to the cut plane, thereby exposing admissible evanescent Bloch modes that contribute to the SB wave. In this way, a reduced-order model (ROM) is developed by the superposition of (admissible) QEP eigenstates to efficiently describe the dispersion characteristics, elastic displacement fields, and penetration depth ("skin depth") of surface Bloch waves. To this end, modal QEP amplitudes are computed by enforcing traction-free boundary conditions at the surface, expanded in Fourier series. This reduced-order representation allows the surface-wave field to be evaluated through a low-dimensional eigenvalue problem, significantly lowering the computational cost while retaining the essential physical features of the full elastic system. The proposed framework enables systematic investigation of the effects of cut-plane orientation and periodic undulation (if any) on the generated SB wave dispersion, localization, and polarization. For completeness, the analysis includes an assessment of energy flux and effective skin depth associated with surface Bloch waves, providing insight into their confinement and transport properties. These quantities are of central importance for the optimal design and control of surface-wave-based functionalities in truncated phononic structures, such as waveguiding filtering, and surface sensing applications.

Speaker



Long Nguyen

University of Minnesota - Twin cities

ID 913: Breaking Passivity Limits in Wave-Based Analog Computing via Complex-Frequency Excitation

9:50 AM – 10:10 AM

Author(s): Moonyeup Shin, School of Civil and Environmental Engineering, Seoul National University; Heedong Goh, School of Civil and Environmental Engineering, Seoul National University

The rising demand for data-intensive processing—driven by machine learning, real-time analytics, and large-scale simulations—has exposed the efficiency bottlenecks of conventional digital logic. In response, wave-based analog computing has emerged as a transformative paradigm, shifting the computational burden from temporal logic gates to the spatial architecture of the medium itself. By exploiting wave–matter interactions within engineered structures, these systems offer the potential for ultrafast, passive, and energy-efficient signal processing. The computational functionality of such systems is encoded in their scattering matrix, which maps incident wave ports to scattered output ports.

However, the design space of these architected materials is fundamentally bounded by intrinsic physical laws, most notably reciprocity and passivity. In a purely passive system, the scattering matrix is strictly contractive, meaning the system cannot inherently amplify signals or implement mathematical operations requiring eigenvalues larger than unity. To overcome this, traditional approaches rely on incorporating active gain media, which introduces significant challenges regarding stability, power consumption, and fabrication complexity.

To address these limitations without resorting to active components, we propose a method to circumvent the passivity constraint by leveraging complex frequency excitation. Unlike conventional steady-state harmonic excitation, complex frequency excitation utilizes waveforms characterized by exponentially growing or decaying temporal envelopes. We demonstrate that this temporal modulation allows a strictly passive architected material to emulate the response of an active system with effective energy gain. By virtually mapping the zeros of the transfer function in the complex plane, we can artificially compensate for material dissipation or realize "virtual gain" required for ill-posed inverse problems.

This approach effectively expands the attainable design space for analog computing platforms, allowing standard passive metamaterials to perform advanced operations previously thought impossible without amplification. We present the theoretical framework and numerical validations of this method, showcasing its application in solving integral equations and performing displacement reconstruction for non-destructive testing. Our findings provide a new perspective on the optimization and computational design of wave-based processors, bridging the gap between passive structural mechanics and active computational requirements.

Speaker



Moonyeup Shin

Mr | Seoul National University

ID 354: A reduced order model of scalar surface Bloch waves in truncated periodic media

10:10 AM – 10:30 AM

Author(s): Prasanna Salasiya, University of Minnesota; Long Nguyen, University of Minnesota; Shixu Meng, University of Texas at Dallas; Bojan Guzina, University of Minnesota

We develop a reduced order model (ROM) describing the boundary layers in truncated periodic media, assuming that the traction-free surface of a periodic medium carries a rational slope relative to its Bravais lattice. The ROM is established as a linear combination of the evanescent Bloch eigenstates solving a quadratic eigenvalue problem (QEP) over the germane unit cell, stemming from a geometric interplay between the mother Bravais lattice and the orientation of the cut surface. The QEP relevant to the development of surface Bloch (SB) waves seeks a complex-valued wavenumber component in the direction orthogonal to the cut surface, given (i) the excitation frequency and (ii) real-valued wavenumber component parallel to the cut surface – corresponding to (prescribed) direction of propagation of the boundary layer. In this vein, the strength of each quadratic eigenstate contributing to the boundary layer is obtained by imposing the homogeneous Neumann boundary condition, expanded in truncated Fourier series. On endowing the cut surface with periodic undulation, it is further shown that the corresponding boundary layer can be evaluated by (i) retaining the original QEP eigenfunction basis, and (ii) recomputing only the (low-dimensional) surface wave eigenvalue problem, given by the Fourier-expanded Neumann boundary condition over the corrugated surface. This feature caters for rapid exploration of the effect of periodic surface undulations and so enables manipulation of the SB waves via optimal design of the surface cut.

Speaker



Prasanna Salasiya

Postdoctoral Associate | University of Minnesota

ID 405: Enabling Advanced Multifunctional Materials Through Synergies of Mechanical Metamaterials and Triboelectric Nanogenerators

10:30 AM – 10:50 AM

Author(s): Roshira Premadasa, New Mexico State University; Qianyun Zhang, New Mexico State University

Abstract

Architected mechanical metamaterials provide unprecedented control over deformation, stiffness, and energy dissipation, yet their functionality remains largely confined to passive mechanical response. This study demonstrates the future of smart materials with a unified material platform that intrinsically couples mechanical programmability with contact-electrification-driven energy transduction, enabling architected structures to harvest energy, sense deformation, and respond intelligently to external loading. By integrating triboelectric nanogenerator mechanisms directly into the cellular architecture, the same unit-cell geometry that governs deformation also controls contact-separation behaviour, charge accumulation, and electrical signal output. We elaborate that mechanical features such as buckling, snap-through, multistability, and surface area modulation can be leveraged to tune triboelectric performance without altering constituent materials. Results reveal that meta-tribo materials achieve controlled stiffness variations, mechanically triggered voltage generation at quasi-static and low-frequency inputs, and sensitivity to localized and global deformation modes. Application demonstrations show capabilities in lightweight load-bearing structures, impact-responsive power generation, self-sensing elements for deformation tracking, and mechanically encoded signal modulation. These findings validate meta-tribo materials as a promising pathway toward multifunctional systems in which structural form, mechanical behavior, and electrical output are co-designed. The presented framework lays the foundation for architected materials that simultaneously operate as sensors, power sources, and mechanical logic elements across civil, mechanical, and bio-medical engineering domains.

Speaker



Roshira Premadasa

Mr | New Mexico State University

ID 601: Enhanced Matrix Interpolation for Dynamic Analysis of Metamaterials

10:50 AM – 11:10 AM

Author(s): Jesus Pereira, University of Michigan - Dearborn; Rafael Ruiz, University of Michigan - Dearborn

Due to the lattice nature of metamaterials, there is an important computational barrier for their effective optimization under uncertainty, requiring the deployment of efficient surrogate models. State-of-the-art approaches for accelerating the frequency response computation of metamaterial structures commonly combine component mode synthesis (CMS) with surrogate models based on simple interpolation or function expansion over a parameterized design. Particularly, strategies leveraging the Craig-Bampton (CB) fixed-interface modal reduction are of interest due to their dynamic interpretation and suitability to create substructure-level surrogate models for metamaterial design. However, these frameworks face an important challenge due to modal interaction via mode crossing and veering triggered by parameter perturbations, resulting in restrictions on the effective size of the model parameter space where these surrogates can be deployed.

Recent interpolation-based parametric reduced-order modeling frameworks mitigate this cost by first reducing each substructure using a CB representation and then learning the parametric dependence of the reduced operators using Principal Component Analysis (PCA) and Kriging regression. Although the effectiveness of this technique for substructures undergoing mode crossing has been proven, a challenge remains regarding the adequate treatment for mode veering situations, where eigenvalue loci rapidly approach and repel while mode shapes undergo sharp rotations. This veering-induced effect on the reduced modal basis can lead to inconsistent modal descriptions across the parameter space, degraded interpolation quality, and large errors in the predicted frequency response functions (FRFs).

To overcome the stated challenge, this work introduces an enhanced interpolation-based surrogate modeling framework explicitly designed to account for mode veering in the substructured dynamics. The proposed approach augments the surrogate definition with veering-aware treatment of the reduced coordinates, enabling stable predictions across parameter regions where conventional mode-by-mode interpolation becomes unreliable. In addition, two additional factors are analyzed to improve the PCA/Kriging workflow, particularly: (1) the usage of adaptive sampling strategies for design-space exploration and surrogate training, concentrating new high-fidelity evaluations in regions indicated to contain veering behavior or elevated surrogate uncertainty, and (2) the impact of PCA normalization choices on surrogate accuracy and robustness.

Speaker



Jesús Pereira

Ph.D. Candidate | University of Michigan - Dearborn

ID 1015: Flexure-induced Architected Instability-based Metamaterials (AIMs)

11:10 AM – 11:30 AM

Author(s): Sibo Zhang, University of Texas at Austin; Yunlan Zhang, University of Texas at Austin; Dominic Vella, University of Oxford

This work introduces a class of flexure-induced architected instability-based metamaterials (AIMs) composed of unit cells with two curved surfaces connected by a stiffer I-shaped frame. These unit cells are designed to transition between stable states primarily through flexural deformation under externally applied moments. We develop an analytical model by describing each curved surface with a trigonometric profile and discretizing it into segments, each modeled as a fixed-fixed curved beam. An energy-based formulation yields the force-displacement response of individual segments, and the overall moment-rotation behavior is obtained by superposition, while accounting for torsional and Poisson effects-induced inter-segment interactions. Finite element simulations and experiments show that peak bearing capacity is strongly governed by the thickness-to-length ratio, whereas bistable snap-through occurs only when the amplitude-to-thickness ratio exceeds a critical threshold and saturates for ratios above 8. Across the investigated design space, the model achieves mean relative errors of 4.9% for peak bearing capacity and 9.5% for bistable ratio, establishing a mechanics-informed analytical framework for multistable flexural AIMs. These findings enable the rational design potential of metamaterials for energy dissipation, adaptive structures, and mechanically tunable systems.

Speaker



Emma Zhang

Assistant Professor | University of Texas at Austin

MS 069: Uncertainty Quantification and System Reliability Methods for Regional Risk and Resilience Assessment

9:30 AM – 11:30 AM | Location: HUMN 150

Chair(s): Sang-ri Yi; Ziqi Wang; Ji-Eun Byun; Alexandros Taflanidis

Moderators



Ji-Eun Byun

Assistant Professor | Imperial College London

ID 211: System Reliability-based Design Optimization of Floating Offshore Wind Turbines Considering Energy Production

9:30 AM – 9:50 AM

Author(s): Junseob Shin, Seoul National University; Seonghyun Lim, Rice University; Junho Song, Seoul National University

Floating offshore wind turbines (FOWTs) present a promising alternative to conventional fixed-bottom turbines for wind energy generation, as higher wind speeds in deep ocean environments enhance energy production. This benefit, however, comes at the cost of intensified environmental loading conditions, which may increase the system failure probability and economic losses. It is also noted that an FOWT structure is a system consisting of multiple components such as blades, towers, generators, and mooring systems, which are made of different materials and serving distinct functions. As the failure of one component may affect the performance of others, a system-level perspective is essential to evaluate the system-level reliability of the structure. Moreover, given that the material selection affects both the structural performance and the energy production efficiency, system reliability-based design optimization (S-RBDO) is also imperative. This is because, if material parameters such as diameter and height are selected solely based on their initial cost, the system may result in higher maintenance demands during operation, thereby reducing its long-term economic benefits. This interdependence between structural reliability, energy output, and economic feasibility makes the optimization problem highly complex and computationally demanding. To overcome this challenge, the proposed S-RBDO framework performs a system reliability analysis to assess the performance of the design of an FOWT under combined wind and wave loading conditions. The environmental loading is modeled using joint probability density functions of 10-minute mean wind speed, significant wave height, and peak period, constructed based on observational data provided by the Korea Meteorological Administration. Dynamic response analysis and energy production are evaluated with OpenFAST, and the simulation results are incorporated into a probabilistic framework to quantify system-level failure probabilities and economic outcomes in RBDO. Based on the proposed probabilistic analysis, the optimal values of the material parameters are identified to satisfy target reliability levels and achieve economic performance objectives. The proposed S-RBDO is expected to support the development of FOWT systems that are both structurally resilient and economically viable under harsh offshore conditions.

Speaker



Junseob Shin

Student | Seoul National University

ID 231: Tensor-based rule extraction for scalable risk assessment of regional-scale infrastructure networks

9:50 AM – 10:10 AM

Author(s): Ji-Eun Byun, University of Glasgow; Hyeuk Ryu, Geoscience Australia; Junho Song, Seoul National University

Accurate system-level risk assessment of complex networks requires evaluating a system performance function, e.g. connectivity or maximum flow, across all possible, or a sufficiently large subset of, combinations of component states. However, the number of such combinations grows exponentially with the number of components, making direct-enumeration-based analysis computationally prohibitive for networks with thousands of components. While a range of advanced sampling techniques has been proposed, the highly discontinuous nature of network system problems often sabotages their effective implementation.

Meanwhile, event decomposition methods offer an alternative by decomposing the system event space into minimal failure and survival rules, defined as the minimal conditions on component state vectors that determine system failure or survival. However, as the number of rules and the resulting decomposed event space grow rapidly with network size, the practical applicability of these methods is typically limited to systems with at most a few hundred components.

To overcome this limitation, we propose a tensor-based rule extraction framework that introduces three key strategies. First, unlike existing event decomposition approaches, the framework separates two tasks: (i) exploration of the system event space for rule extraction and (ii) probabilistic inference of quantities of interest, e.g. system failure probability. Once extracted, the rules can be reused across repeated evaluations with evolving component probabilities, eliminating the need for repeated rule identification—a key advantage over sampling-based approaches.

Second, whereas existing event decomposition methods rely on analytical searches of the system event space, which becomes a computational bottleneck for large systems, we introduce a novel stochastic search strategy for rule extraction that scales more effectively with system size. Finally, all operations are formulated as tensor computations, enabling efficient execution via GPU acceleration and batched tensor operations, and allowing the framework to directly benefit from advances in state-of-the-art computing hardware.

We demonstrate the scalability of the proposed method by evaluating networks with thousands of components within a few minutes. The proposed technology provides the potential for real-time risk mapping technology for complex large-scale infrastructure networks. Building on this capability, this presentation also discusses its implications for decision supports, with particular attention to disaster equity.

Speaker



Ji-Eun Byun

Assistant Professor | Imperial College London

ID 590: Regional Risk Assessment of Rainfall-Induced Cut-Slope Failures: Methodology Validation and Application to Chile

10:10 AM – 10:30 AM

Author(s): Manuel Contreras-Jara, School of Engineering, Pontificia Universidad Católica de Chile & CIGIDEN R+, Chile; Alondra Chamorro, School of Engineering, Pontificia Universidad Católica de Chile & CIGIDEN R+, Chile; Esteban Saez, School of Engineering, Pontificia Universidad Católica de Chile & CIGIDEN R+, Chile.; Tomás Echaveguren, Engineering Faculty, Universidad de Concepción & CIGIDEN R+, Chile.; Cristina Torres-Machi, Department of Civil, Environmental, and Architectural Engineering, Univ. of Colorado Boulder

Natural hazards related to precipitation pose a significant risk to transport infrastructure, mainly due to landslides on road networks. Landslides caused by rainfall are recurrent, resulting in traffic disruptions that lead to economic costs and safety issues. Existing frameworks often lack a comprehensive probabilistic assessment that links the physical probability of landslides to operational consequences at the network scale. As climate change intensifies and increases the frequency of extreme rainfall events, there is an urgent need to develop methods that incorporate uncertainty into risk modeling and quantify the recurring impacts on regional transport resilience.

Despite advances in the analysis of specific cut-slope stability, the application of these models to regional scale risk assessments remains limited. Current approaches tend to focus separately on the probabilities of physical failure or operational impacts, without sufficiently integrating the stochastic nature of precipitation and the heterogeneity of slopes across large geographic regions. Recent advances in probabilistic modeling, fragility curves, and infrastructure information systems enable a transition to more holistic, uncertainty-based risk assessments. However, the evaluation of mitigation measures within regional risk frameworks remains underdeveloped.

This study presents a novel methodology for assessing traffic disruptions caused by rain-induced cut-slope failures at the regional scale, with a comparison between the southern of Chile and Alaska. The primary objectives are to apply physics-based fragility models for slopes, estimate the probabilities of landslides associated with extreme rainfall events, simulate the resulting road disruptions and increased travel times, and assess the effectiveness of mitigation measures in reducing the vulnerability of the network. The methodology integrates risk modeling using synthetic rainfall scenarios derived from regional rainfall data and IDF curves, along with a probabilistic assessment of slope stability through limit equilibrium and finite element analyses. The extent of traffic disruption is quantified through simulations using the material point method of landslide runoff, which are related to operational impacts through traffic diversion models. Mitigation strategies, including slope reinforcement and retaining walls, are evaluated in terms of their effectiveness in reducing traffic disruptions.

Applied to the case study regions, the framework demonstrates the ability to identify vulnerable cut-slopes and critical road sections over various return periods ranging from 5 to 100 years. The results indicate that the probability of landslides and consequent travel times increases significantly with rainfall intensity, with a potential increase of more than 40% in extreme situations. The regional comparison highlights how different geomorphological and climatic conditions influence slope vulnerability and network resilience. This approach enables decision-makers to prioritize mitigation measures and develop cost-effective adaptive management strategies based on physically based risk estimates that account for uncertainty.

Speaker



Manuel Contreras Jara

PhD Student, Civil Engineer | Pontificia Universidad Católica de Chile

ID 361: Comprehensive Uncertainty Quantification for Regional Seismic Risk Assessment of Bridge Networks

10:30 AM – 10:50 AM

Author(s): Esteban Amaya, University of Notre Dame; Alexandros Taflanidis, University of Notre Dame

Regional seismic risk assessment of bridge networks requires accounting for multiple sources of uncertainty, including ground-motion variability, structural response, and consequence modeling. Probabilistic simulation frameworks are commonly adopted to propagate these uncertainties; however, their computational demands often require simplifying assumptions, such as partial uncertainty propagation, scenario reductions, or structural modeling simplifications. While such modeling choices are practical, they can materially affect risk estimates. This study presents a comprehensive uncertainty quantification framework for regional seismic risk assessment of bridge networks that explicitly evaluates how distinct uncertainty sources contribute to total regional risk and how different uncertainty propagation assumptions bias the estimated risk.

The Chilean bridge network is considered as case study. To promote computational efficiency in the risk assessment, a stochastic emulator surrogate model is implemented to predict distributions of engineering demand parameters (EDPs) across variable bridge configurations while incorporating uncertainties in structural attributes and seismic input. The accuracy of the surrogate model is first validated against high-fidelity simulations. Then, the surrogate model is used to conduct Monte Carlo simulations to estimate network-level seismic losses. Multiple variants are considered to represent alternative uncertainty propagation assumptions and to quantify their influence on regional risk outcomes. Results demonstrate the impact of different uncertainties on the risk estimates and identify the uncertainty sources that most strongly control network risk, thereby providing crucial insights for more reliable regional assessments.

Speaker



Esteban Amaya

PhD(c) | University of Notre Dame

ID 532: Stochastic Emulation for Seismic Risk Assessment and the Impact of Intensity Measure Selection

10:50 AM – 11:10 AM

Author(s): Sang-ri Yi, Rice University; Parisa Toofani Movaghar, University of Notre Dame; Alexandros Taflanidis, University of Notre Dame; Carmine Galasso, University College London; Dimitrios Vamvatsikos, National Technical University of Athens

Surrogate modeling has become an effective approach for expediting probabilistic seismic risk assessment by enabling the emulation of structural responses using a limited set of computationally expensive nonlinear time-history analyses. One approach to develop a surrogate model for this type of application is by establishing a stochastic mapping that links a low-dimensional input vector, composed of ground-motion intensity measures (IMs) and structural parameters, to peak engineering demand parameters (EDPs), following the principles of traditional seismic fragility analysis. A major consideration when establishing this mapping is the accurate prediction of record-to-record variability, which represents an aleatoric source of uncertainty in surrogate model development. When this uncertainty is heteroskedastic across the parameter space, a special surrogate modeling approach called stochastic emulation needs to be utilized. The characteristics of the aleatoric uncertainty, particularly its magnitude and heteroskedasticity, depend on the selection of IMs. This work investigates the three-way coupling between IM selection, characteristics of aleatoric variability, and surrogate performance, thereby providing recommendations for IM selection and the required properties of stochastic emulators to achieve the desired performance. This is facilitated by a Gaussian process-based stochastic emulator that flexibly describes the heteroskedasticity of second-order moments associated with the aleatory uncertainty. It is shown that the substantial impact of IM choice on the aleatoric uncertainty characteristics of EDPs leads to different preferences for emulator characteristics and varying accuracy expectations.

Speaker



Sang-ri Yi

Assistant Professor | Rice University

Careers & Mentorship: Insights and Advice

9:30 AM – 11:00 AM | Location: HUMN 1B90

This panel brings together EMI members to share insights on career paths, mentorship, and professional growth. Panelists will reflect on the challenges and rewards of their journeys, discuss the role of mentorship at different career stages, and offer practical advice for early-career scientists. The session will provide an opportunity to engage with leaders in the EMI community, ask questions, and build connections. Hosted by the EMI Mentoring and Early Career Advancement Committee

Speaker



Arghavan Louhghalam

UMass Lowell

MS 070: Probabilistic assessment, data-driven inference, and optimization for decision-making under uncertainty

9:30 AM – 11:30 AM | Location: CLUB 4-5

Chair(s): Kostas G. Papakonstantinou; Charalampos P. Andriotis; Dan M. Frangopol; George Deodatis

Moderators



Kostas Papakonstantinou

Associate Professor | Penn State University

ID 129: Reliability-based calibration of imposed loads for office buildings

9:30 AM – 9:50 AM

Author(s): James Whiteley, University of Cambridge; Will Hawkins, University of Bath; Jurgen Becque, University of Cambridge; Josephine Carstensen, Massachusetts Institute of Technology; David Watson, AKT II

Imposed loads are the variable actions arising from the use of buildings, including the weight of occupants, furniture and moveable partitions. The characteristic values specified in structural design codes are typically calibrated using historical loading data and empirical justifications that may no longer reflect current occupancy patterns. This study presents a data-driven, reliability-based calibration of imposed loads specific to UK office buildings, using recent survey data collected by the coauthors. This work aims to support informed decision-making in relation to potential updates to the UK National Annex to EN 1991-1-1.

The calibration methodology uses load statistics derived from recent survey data with established probabilistic approaches to code calibration. Loading variability is first considered in isolation through a load-side approach consistent with conventional methods of Eurocode partial safety factor calibration. Subsequently, the reliability of steel structural members is assessed by combining loading and resistance uncertainties within a First-Order Reliability Method analysis. Both approaches are used to inform characteristic imposed load values consistent with Eurocode target reliabilities. Frequent and quasi-permanent factors for serviceability limit state design are also derived.

A second objective concerns multi-storey load reduction factors, which permit reduced imposed loads when designing members supporting multiple floors, reflecting the low probability of simultaneous maximum loading across all storeys. In the absence of extensive survey data capturing inter-storey correlations, a parametric investigation is conducted to assess the sensitivity of current reduction curves to various correlation assumptions. This analysis provides insight into the value of additional data collection for refining these provisions.

The results demonstrate how characteristic values derived from contemporary loading data differ from those currently codified, with implications for both structural economy and reliability. Recommendations are offered for the characteristic value of imposed loading, frequent and quasi-permanent factors and storey-based reduction curves appropriate to modern office buildings.

Speaker



James Whiteley

PhD Student | University of Cambridge

ID 309: Stochastic Modeling of Microdamage Evolution in Steel Fiber Reinforced Concrete using Acoustic Emissions

9:50 AM – 10:10 AM

Author(s): Nikhil Gupta, Indian Institute of Science, Bangalore; Vidya Sagar Remalli, Indian Institute of Science, Bangalore; Chandra Kishen J. M., Indian Institute of Science, Bangalore

The article reports on stochastic modeling of microdamage evolution in steel fiber reinforced concrete (SFRC) under Mode I crack deformation. The fracture processes and damage evolution in SFRC remains a research problem due to the inherently random nature of microcracking and steel fiber–cementitious matrix interactions. Despite the widespread use of acoustic emission (AE) monitoring for microdamage detection, quantitative stochastic models relating AE waveforms to fracture behavior are limited. In this study, a stochastic failure approach is introduced to analyze the recorded AE data. AE events are interpreted as a stochastic sequence of micro failure processes that evolve randomly with increasing deformation. This evolution is modeled using a non-homogeneous renewal Markov process, mathematically described as a doubly stochastic Poisson process. The model is governed by two parameters that characterize the initial resistance to microcracking and the rate of damage growth. These parameters are estimated at each crack mouth opening displacement (CMOD) increment to estimate micro failures observed in AE event sequences. It was observed that the cumulative AE events increase sharply near the onset of macroscopic failure, consistent with the damage. AE energy distributions follow a Pareto-type power law for all specimens. Increasing steel fiber content changes the stochastic parameters, reducing the damage growth rate and increasing the CMOD at macroscopic failure. This behavior reflects the ability of steel fibers to bridge cracks, redistribute stresses, and arrest microcrack growth. From the stochastic model perspective, the presence of steel fibers can be interpreted as a repair like mechanism that delays fracture processes and accumulation of micro failures. The used stochastic approach provides a quantitative basis for comparing fracture process for different SFRC mixtures and highlights the role of fibers in enhancing fracture resistance.

Speaker



Nikhil Gupta

Mr. | Indian Institute of Science, Bangalore, India

ID 901: Incorporating Structure-Dependent Hazard and Structural Parameter Uncertainty in the Performance-Based Earthquake Engineering Framework

10:10 AM – 10:30 AM

Author(s): Lei Zhou, University of California, Davis; Maria Jose Echeverria, California State University, Sacramento; Michele Barbato, University of California, Davis

Performance-Based Earthquake Engineering (PBEE) provides a probabilistic framework for evaluating seismic performance by combining hazard characterization, structural response analysis, and damage assessment. In current PBEE practice, seismic hazard is typically characterized independently of structural properties, whereas uncertainty in structural parameters is introduced primarily during response and damage analysis. However, when structure-dependent intensity measures are employed (e.g., pseudo-spectral acceleration evaluated at the structure's fundamental period T and damping ratio ζ , $S_a(T, \zeta)$), uncertainty in those parameters introduces additional variability into the hazard input, which is not explicitly represented in conventional PBEE formulations.

To address this issue, an extended PBEE (X-PBEE) framework is proposed in which the interaction between hazard and structural uncertainty is explicitly accounted for through an intermediate pairing step. Structural realizations are matched with corresponding intensity measure values based on the parameters that influence the intensity measure (e.g., natural period and damping ratio), allowing uncertainty in structural properties to propagate into the seismic input used for response analysis while preserving the independence of the original hazard description. This formulation is consistent with approaches previously adopted in performance-based wind and hurricane engineering.

The framework is demonstrated using both linear and nonlinear single-degree-of-freedom (SDOF) systems subjected to suites of recorded ground motions. Three analysis cases are compared: (1) deterministic structures defined by mean structural properties, T_0 and ζ_0 ; (2) random structures analyzed using a conventional PBEE approach, in which the pseudo-spectral acceleration is evaluated at mean period and damping ratio, $S_a(T_0, \zeta_0)$; and (3) random structures analyzed using the X-PBEE approach, in which the pseudo-spectral acceleration is evaluated at the randomly sampled period and damping ratio for each structural realization, $S_a(T, \zeta)$.

For the linear systems, T and ζ are modeled as lognormally distributed random variables with prescribed means and coefficients of variation (CV). The three analysis cases produce similar median S_a capacity, λ ; however, they provide significantly different S_a logarithmic dispersions, β . The deterministic case has zero dispersion, as the capacity is a direct function of limit state displacement and natural period of the structure. The conventional PBEE formulation exhibits larger dispersions at short periods and for lightly damped systems, with dispersions decreasing as the period increases. The X-PBEE analysis produces a constant dispersion value that depends only on the variability of the natural period.

For the nonlinear systems, T is modeled as a normally distributed random variable with mean $T_0 = 0.1$ s and $CV = 0.1$, whereas ζ is kept constant and equal to 5%. Multiple damage limit states and response-modification factors are considered. The results for this case study show that using the X-PBEE methodology produces only modest changes in λ but leads to consistent reductions in β when compared to those obtained by using the conventional PBEE formulation. These reductions are most pronounced at limit states corresponding to lower deformations. Further studies are ongoing to investigate the sensitivity of the results to different natural periods and damping ratios, and the effects of using X-PBEE instead of conventional PBEE on the distributions of decision variables (e.g., expected losses).

Speaker



Maria Jose Echeverria

Assistant Professor | California State University, Sacramento

ID 724: Higher-Order Statistical Characterization of Tropical Cyclone Extremes Using Generalized Linear Models and Machine Learning Approaches

10:30 AM – 10:50 AM

Author(s): Yu Chang, Tsinghua University; Jiayao Wang, University of Notre Dame; Sunwei Li, Tsinghua University

Traditional research on tropical cyclone (TC) climatology has predominantly focused on lower-order statistical characteristics of atmospheric variables, such as the mean and variance, leaving the role of higher-order moments, skewness and kurtosis, largely under-explored. This study investigates the evolving impact of higher-order atmospheric variability on TC extremes in the South China Sea from 1993 to 2022. By analyzing 30 years of monthly data across multiple vertical levels, we examine the relationship between the statistical moments of key environmental variables (temperature, zonal wind, and meridional wind) and the frequency of TC-induced extreme events. The research employs a comparative framework utilizing L1-regularized Poisson Generalized Linear Models (GLM) for feature selection alongside XGBoost machine learning models, integrated with the SHAP (SHapley Additive exPlanations) interpretability framework. While annual TC frequency shows no significant trend, the proportion of intense (Category 4 and 5) typhoons has increased substantially. Our findings reveal a critical seasonal reversal in the predictive power of atmospheric moments: during the peak season (July–August), higher-order moments capture non-Gaussian distributional tails and contribute over 64% to the predictive performance. Conversely, lower-order moments dominate during the shoulder seasons (June and October). This regime shift statistically links the intensification of TC hazards to an environment where higher-order variability plays an increasingly decisive role. These results underscore the necessity of incorporating higher-order statistical features into diagnostic and predictive frameworks to improve the assessment of evolving TC risks and extreme weather events.

Speaker



Yu (Alice) Chang

PhD Candidate | Tsinghua University

ID 771: Residual drift-informed nonlinear structural model parameter updating and its effect on aftershock performance and risk

10:50 AM – 11:10 AM

Author(s): Budhaditya De, University of California, Los Angeles; Henry Burton, University of California, Los Angeles

Aftershock risk assessment is a critical component of post-earthquake decision-making for infrastructure management. Traditionally, such assessments rely on structural models calibrated to pre-event expected properties, which do not make use of the information that can be inferred from the mainshock response and damage. Recent studies have demonstrated that residual drifts measured after a damaging earthquake can be used as an effective source of information for parameter updating, enabling the refinement of nonlinear structural models.

This paper investigates the implications of using the posterior (in lieu of prior or pre-event) distribution of nonlinear model parameters in aftershock risk assessments. Data from a bridge pier tested at the University of California, San Diego are first used to benchmark the prior and posterior distributions of the nonlinear structural model parameters. The latter is obtained using a Bayesian framework that is informed by measured residual drifts after each successive record in the ground motion sequence used in the experiment. Aftershock risk assessments are then performed on a complete 3D bridge structural model using both the pre- and post-updated parameters. The quantified performance is compared based on the probability distribution of key engineering demand parameters, fragility functions produced for a range of limit states, and risk-based metrics that account for the time-dependent seismic hazard. The study aims to highlight the importance of integrating post-mainshock model updating into aftershock risk frameworks and underscores the value of residual drift measurements, which are now obtainable via technologies such as LiDAR or drone imaging.

Speaker



Budhaditya De

Mr. | University of California, Los Angeles

ID 826: Lifetime Reliability Versus Annual Risk: How ASCE SEI Live Loads Should be Changed

11:10 AM – 11:30 AM

Author(s): Sanjay Arwade, University of Massachusetts Amherst; Ross Corotis, University of Colorado Boulder; Khanh Duy Ha, University of Massachusetts Amherst

Among many challenges in setting design loads for the ASCE SEI 7 Standard, the role of nonstationarity has never been addressed for live loads. This simplification has enabled one-to-one correspondence between annual risk and lifetime reliability. While such an approach represents a naturally reasonable generalization, the authors have recently encountered an interesting challenge in a project sponsored by the Pankow Foundation related to parking garage live loads, which may evolve over time as vehicle fleet characteristics change. Key in this situation of life-cycle infrastructure management risk and reliability assessment are stochastic modeling and simulation, uncertainty quantification and propagation, data-driven inference and model updating.

Vehicle purchasing preferences have changed significantly over the past few decades. Individual models of vehicles have gotten heavier, around 15% since the turn of the century, and in addition, preferences have moved from sedans to SUVs and pickup trucks. In addition, the increased weight of electric vehicles (EVs) relative to similarly sized internal combustion engine vehicles presents an evolving increase with projected market penetration. The additional weight of these vehicles presents a paradigm shift with their introduction and potential eventual domination of the market.

So, the interesting challenge is stochastic uncertainty for future loads, uncertainty propagation, reliability assessment and evolving risk over the design lifetime of constructed facilities. A stochastic model incorporating extreme value analysis is implemented for parking garage live loads and the vehicle databases and distributions. In addition to uniform, random, assignment of vehicles to parking spaces in the model, the special case corresponding to EV concentration around charging stations is investigated. The key question for standards-writing committees is how to specify design loads for today that will account for changes in load intensity over the lifetime of the built structure. At the heart of the design decision are two extremes. One extreme is the requirement to demand that current design use projected future load increases over a design lifetime. At the other extreme is the allowance of the increased risk incurred using current load characteristics that might be inadequate over the design lifetime. The former is likely to lead to a significant increase in resources, whereas the latter might lead to unsatisfactory future reliability.

Speaker



Khanh Duy Ha

Graduate Student | University of Massachusetts Amherst

MS 042: 24th Symposium on Biological and Biologically Inspired Materials and Structures

9:30 AM – 11:30 AM | Location: CASE E230

Chair(s): Dinesh Katti; Christian Hellmich

Moderators



Dinesh Katti

Professor | North Dakota State University

ID 252: Establishing Design Principles for Mechanosensitive Living-Light Materials

9:30 AM – 9:50 AM

Author(s): Giulia Brachi, University of Colorado Boulder; Cheng Pau Lee, University of Colorado Boulder; Jessica McKean, University of Colorado Boulder; Joy Chinazaekpere Edwin-Ezeh, University of Colorado Boulder; Wil V. Srubar III, University of Colorado Boulder

Establishing Design Principles for Mechanosensitive Living-Light Materials

Giulia Brachi*, Cheng-Pau Lee*, Jessica McKean, Joy Chinazaekpere Edwin-Ezeh, Wil V. Srubar III

Bioluminescent dinoflagellates exhibit near-instantaneous light emission in response to mechanical stimulation, making them ideal candidates for mechanoresponsive living materials. Embedding these microorganisms within soft matrices offers a promising route to engineer adaptive light-emitting systems for applications spanning soft robotics, environmental monitoring, and biomedical diagnostics. However, rational design principles linking matrix mechanics and stimulation strategies to bioluminescent output remain poorly explored.

Here, we address this gap by establishing design rules for dinoflagellate-based living-light materials through a systematic investigation of how hydrogel mechanics and hybrid activation strategies govern mechanotransduction and light emission.

Pyrocystis lunula was encapsulated within biocompatible alginate hydrogels, with varying gelatin content (10-40% w/v) introduced to form double-network matrices that enable precise tuning of matrix stiffness. Quantitative measurements under controlled compressive stress revealed that increasing matrix stiffness requires greater deformation to trigger light emission, as stiffer networks impose higher mechanical resistance prior to activation. These findings identify hydrogel mechanics as a key design parameter governing mechanosensitive bioluminescence.

To further amplify and sustain light output, we implemented a dual-mode activation strategy combining mechanical deformation with chemical stimulation. While mechanical inputs alone elicited rapid bioluminescent responses, the addition of chemical stimulation produced a synergistic effect, resulting in more than a two-fold increase in total luminescent output compared to mechanical compression alone. This hybrid approach enables enhanced control over both the intensity and duration of light emission in living-light materials.

Finally, we demonstrate proof-of-concept applications by fabricating patterned bioluminescent structures that emit light upon localized compression and strain-responsive hollow fibers produced via co-extrusion to enable real-time mechanical stress visualization. Together, these results establish foundational design principles for dinoflagellate-based living-light materials and highlight their potential as programmable, mechanoresponsive systems for biohybrid technologies.

Speaker



Giulia Brachi

Research Associate | University of Colorado Boulder

ID 935: Controlling Ionic Fluxes in Charge-Patterned Wavy Nanochannels

9:50 AM – 10:10 AM

Author(s): Pouya Golchin, Sonny Astani Department of Civil and Environmental Engineering, University of Southern California; Jinwoo Im, Lawrence Berkely National Lab; Felipe P. J. de Barros, Sonny Astani Department of Civil and Environmental Engineering, University of Southern California; Thomas Petersen, Sonny Astani Department of Civil and Environmental Engineering, Department of Aerospace and Mechanical Engineering, University of Southern California

In biological systems, selective transport across membranes relies on precise electrochemical control of flow through nanoscale pores: ion channels regulate neural signaling by gating charged species, membrane pores mediate selective biomolecule transport during cellular uptake and secretion, and protein-based nanopores achieve high ionic selectivity through a combination of confinement and patterned surface charge. Analogously, many engineered systems benefit from technological improvements in controlling electrochemical transport through pores. Contaminant remediation in the subsurface often requires redirecting flow patterns of charged scalar tracers; enhanced oil recovery imposes osmotic pressure gradients that aim to increase hydrocarbon release from tight pore networks; and ion-exchange membranes rely on maximizing the selective throughput of cations or anions through a polymer matrix.

The current study inspects the interplay between oscillations in geometry and surface charge density in controlling ionic currents through nanochannels. To do so, the Poisson–Nernst–Planck–Stokes equations are solved numerically under conditions of varying aperture profile, salt concentration, and charge placement. Flow is driven by a combination of a prescribed pressure gradient and an external electric field. We reproduce recent observations of a gating mechanism that transitions between regimes of electrostatically inhibited and electromechanically dominated flow. Upon marginally increasing the magnitude of the pressure gradient or applied electric field along the channel axis, the mean velocity jumps by orders of magnitude. Combined control of the geometrical aperture profile and the placement of charge patches produces an electrochemical diode that rectifies flow in a preferred direction. By investigating the transport of the ionic species separately, we demonstrate the importance of surface charge patterning in optimizing ionic current selectivity. Interestingly, the highest selectivity is achieved upon approaching the flow transition. Fluid velocity profiles are combined with a Brownian particle tracking algorithm to resolve transport statistics for prescribed pressure gradients and externally controlled electric fields. These results demonstrate that patterning surface charge is essential for optimizing ionic selectivity and for designing next-generation nanofluidic devices.

Speaker



Thomas Petersen

Assistant Professor | USC

ID 499: Development of Flexible Tactile Sensors Based on Electrical Impedance Tomography

10:10 AM – 10:30 AM

Author(s): Paul Choi, Department of Electrical and Computer Engineering, The University of Texas Rio Grande Valley; John Acevedo, Department of Civil Engineering, The University of Texas Rio Grande Valley; Philip Park, Department of Civil Engineering, The University of Texas Rio Grande Valley

Electronic films integrated with electrical impedance tomography (EIT) are advanced sensing systems designed to mimic the sensory functions of human skin while enabling spatially resolved electrical measurements. These systems consist of stretchable, skin-conformal electrode arrays embedded within soft substrates that can comfortably adhere to curved and dynamic surfaces. By injecting small electrical currents through selected electrodes and measuring the resulting voltage responses at others, EIT reconstructs conductivity or impedance distributions across the electronic film surface. The integration of EIT with electronic films allows for real-time, high-resolution mapping of mechanical stimuli such as pressure, strain, touch, and deformation, as well as physiological signals. Changes in contact force, material deformation, or underlying biological activity alter the local electrical impedance, which can be imaged using EIT algorithms. This approach reduces wiring complexity compared to individually addressed sensor arrays, enhances robustness against mechanical damage, and enables scalable, large-area sensing. Electronic films with EIT capability are particularly promising for applications in wearable health monitoring, human-machine interfaces, soft robotics, and prosthetics, where conformability, sensitivity, and spatial awareness are critical. By combining soft electronics with tomographic imaging techniques, EIT-based electronic films provide a powerful platform for continuous, noninvasive, and distributed sensing.

We have developed five different electronic films with different configurations of conductive materials embedded in a flexible base material to analyze their properties and identify the device with the best EIT sensing performance for tactile sensing. The base material was fixed as polydimethylsiloxane (PDMS), which is a flexible and biocompatible material. PDMS has been widely used in a variety of applications, including implantable devices, microfluidic systems, and electronic insulation materials. Three different conductive materials were used: 150 μm diameter microwires, carbon fibers, and carbon powder. Two of the five configurations consist of combinations of microwires with carbon fibers and microwires with carbon powder. The remaining three devices were fabricated using a single conductive material. All five devices have 16 output electrodes connected to a commercially available EIT measurement system (EIT64, Sciospec Scientific Instruments GmbH, Bennewitz, Germany) to evaluate device performance. The initial application of these electronic films is as tactile sensors that exhibit changes in impedance when the surface morphology of the flexible devices is altered by physical touch, with millimeter-scale indentation. We found that the device fabricated using carbon powder alone is most suitable for tactile sensing, as it provides a conformal distribution of conductive material throughout the PDMS structure, resulting in similar ranges of electrical signal variation when the device is touched at random locations.

Speaker



John Alfred Acevedo

PhD Student | University of Texas at Rio Grande Valley

ID 524: “Bio-metals”: Uncovering ancient biological materials with nanoindentation size effects arising from manifold micromechanics

10:30 AM – 10:50 AM

Author(s): Christian Hellmich, TU Wien (Vienna University of Technology); Luis Zelaya-Lainez, TU Wien (Vienna University of Technology); Friedrich Schuster, TU Wien (Vienna University of Technology); Stefan Manhartseder, TU Wien (Vienna University of Technology); Maximilian Landegger, TU Wien (Vienna University of Technology); Kyojiro Ikeda, University of Vienna; Florian Raible, University of Vienna; Olaf Lahayne, TU Wien (Vienna University of Technology); Stefan Scheiner, TU Wien (Vienna University of Technology)

The Nix-Gao nanoindentation size effect [1], where squared hardness scales with the inverse of the indentation depth, qualifies as a major hallmark of crystalline metals. The effect arises from the accumulation of dislocations, i.e., irregularities in the atomic lattice in the form of line defects, in the material located right below the indenter. We here show that the very same effect holds for a totally different type of material, namely the one making up the jaws of the bristle worm *Perinereis cultrifera*. After lysis and embedding into a two-component resin, both the resin surface and the jaw itself were abraded, providing a flat surface with a roughness of only 30 nanometers of the material found in the mid-plane of the jaw. Prior work [2] suggests that this material is formed by an unusual class of proteins coordinated by transition metals and halogen ions. The flat surface was nanoindented down to six different indentation depths at eleven specific testing areas, covering the central and tip regions of the jaw. As a rule, 54 indentations were realized per indentation depth and area. Both in the tip and the central region, the hardness-to-depth relations clearly obey the Nix-Gao size effect law, which is classically linked to strain gradient plasticity. Interestingly, our experiments also reveal an elastic size effect. The latter is rationalized in the framework of “manifold micromechanics”: Concentrated microscopic volume forces of the Peach-Koehler type [3], situated at dislocation-type “folds” in the ion-coordinated structural protein matrix, induce non-negligible macroscopic strain gradients at the level of a representative volume element (RVE) of the matrix that we suggest referring to as “bio-metal”.

[1] W. D. Nix, H. Gao, Indentation size effects in crystalline materials: A law for strain gradient plasticity, *JMPS*, Vol. 46, pp. 411-425, 1998.

[2] L. Zelaya-Lainez, G. Balduzzi, O. Lahayne, K. Ikeda, F. Raible, C. Herzig, W. Nischkauer, A. Limbeck, and C. Hellmich, Jaws of *Platynereis dumerilii*: Miniature biogenic structures with hardness properties similar to those of crystalline metals, *JOM*, Vol. 73, pp. 2390–2402, 2021.

[3] M. Peach, J. S. Koehler, The forces exerted on dislocations and the stress fields produced by them, *Phys. Rev.*, Vol. 80, pp. 436-439, 1950.

Speaker



Christian Hellmich

Prof. | TU Wien/IMWS

ID 630: The effects of the chemical composition of human bone on its nanoscale mechanical properties

10:50 AM – 11:10 AM

Author(s): Elisa Budyn, Ecole Normale Supérieure Paris-Saclay; Ana Chee, Rush University Medical Center; Arnavaz Hakimiyan, Rush University Medical Center; Shelby Pietro del Rivero, Rush University Medical Center; Romain Dupouy, Ecole Normale Supérieure Paris-Saclay; Elias Aloai-Chrifi, Ecole Normale Supérieure Paris-Saclay; Christophe Sandt, SOLEIL synchrotron; James Williams, Rush University Medical Center; Susan Chubinskaya, The University of Texas Medical Branch Galveston; Brian David, Rush University Medical Center

Aging and many degenerative pathologies affect bone homeostasis, its chemical composition, and its material and mechanical properties. Understanding how these properties are related to each other could lead to the identification of biochemical biomarkers of aging, along with certain pathologies, as well as contribute to the explanation, treatment, and prevention of future bone damage, particularly in the elderly.

Chemical characterization was possible by applying super-resolution infrared micro-spectroscopy technique, known as Optical Photothermal Infra-Red Spectroscopy (O-PTIR), on millimeter-sized samples prepared from human cadaver bones of known sex, age, and pathology. Both explants and tissue samples, that were later recut into prisms to prepare organoids from cadavers, were collected within 10 days of death, following extraction by Liston bone forceps, and kept alive for four months before O-PTIR analysis. As bone constitutes a physiologically relevant 3D in vitro environment, the prismatic tissue samples were subsequently used to create bone organoids, by decellularizing and re-seeding the tissue with adult human primary mesenchymal stem cells (MSCs) from different donors (of different ages and sex). MSCs differentiated into stem cell-derived osteocytes within 30 days, then formed new bone tissue that was analyzed via O-PTIR. Some of the cadaveric tissue samples were directly analyzed with O-PTIR either after collection or decellularization for control. Secondly, local mechanical characterization was possible by using the Finite Element Model (FEM) of the bone extracellular matrix (ECM), which was built to visualize the mechanical 3D stress field inside a volume of tissue approximating O-PTIR spatial resolution. The numerical model was generated using morphological data from TEM imaging, along with the material properties inferred by the chemical data measured by O-PTIR. AI-based statistical analyses identified sub-families among O-PTIR spectra and extracted variations in the chemical compositions, such as the relative contents of collagen, minerals, and fat, among donors of different age groups.

Both the collagen/mineral ratio and fat content tended to increase with age and negatively impact the local stress fields around bone cells. The FEM model showed that the bone adapts its collagen orientation to the most suitable angle to bear lower stresses (either tension or compression). Finally, biomarker gene expression was measured via qPCR of the bone cells of the different age groups and was then correlated with the O-PTIR results.

CNRS INSIS PEPS, SOLEIL 20191708, 20201633, 20230772, 20231906 awards, the Anatomical Gift Association of Illinois, and the Gift of Hope Organ and Tissue Donor Network and Donor's Family are acknowledged.

Speaker



Elisa Budyn

Professor | Ecole Normale Supérieure Paris-Saclay

ID 635: Finite Element Analysis of Brain Tissue Mechanics for Traumatic Brain Injury Assessment

11:10 AM – 11:30 AM

Author(s): Sujata Ghimire, University of New Mexico; Madura Pathirage, University of New Mexico

Traumatic brain injury (TBI) arises from complex mechanical interactions within brain tissues subjected to loading events. The brain is a soft, heterogeneous biological material whose response is governed by rate-dependent behavior, regional material variation, and interactions with surrounding structures such as the skull and cerebrospinal fluid. Understanding how these mechanical features influence injury mechanisms is essential for improving TBI assessment and interpretation. Current injury assessment approaches rely largely on single-value kinematic or tissue-level thresholds, such as peak acceleration, strain, or stress, to infer injury severity. While these metrics are widely used, they often provide inconsistent or contradictory predictions for identical impact events and do not fully reflect the time-dependent and spatially distributed nature of brain tissue response. This limitation highlights a critical knowledge gap in relating the mechanics of brain tissues to injury mechanisms in a physically meaningful manner.

In this work, a mechanics-based framework is developed to examine the time-history based response of brain tissues under impact loading using high-fidelity finite element modeling. An anatomically detailed head model is constructed with explicit representation of the skull, cerebrospinal fluid, and multiple brain regions, each assigned constitutive behavior consistent with their mechanical function. Brain tissues are modeled using viscoelastic material formulations to capture rate-dependent response, while the skull is represented with elastoplastic behavior to account for nonlinear deformation. This modeling approach enables investigation of stress, strain, and kinematic fields as they evolve in both space and time, allowing direct examination of tissue-level mechanics throughout the impact event rather than reliance on peak response measures alone.

To address limitations of existing injury metrics, the study focuses on analyzing key characteristics of brain tissue response, including stress wave propagation, loading duration, and spatial redistribution of deformation. Time histories of stress and strain reveal response patterns that are not captured by single-value thresholds and that vary across brain regions with different material behavior. These observations motivate the exploration of an integrated injury indicator that combines multiple biomechanical measures with time-dependent characteristics, providing a more consistent interpretation of tissue-level injury risk without assuming a single dominant threshold.

The proposed framework is demonstrated using a reconstructed cyclist head impact scenario as an application case, where identical loading conditions are applied with and without a helmet. This scenario provides a realistic mechanical loading context for examining time-dependent brain tissue response and evaluating the behavior of injury metrics under comparable conditions. Overall, this study emphasizes the importance of treating the brain as a complex biological material system governed by time-dependent mechanics and provides a foundation for improved evaluation of TBI grounded in brain tissue behavior rather than isolated peak metrics.

Speaker



Sujata Ghimire

Research Assistant | University of New Mexico

MS 055: Optimization in Civil Engineering: Methods, Challenges and Solutions

9:30 AM – 11:30 AM | Location: CASE E240

Chair(s): Yakov Zelickman; Edvard Bruun; Josephine Carstensen

Moderators



Yakov Zelickman

Dr. | Johns Hopkins University

ID 156: An Integrated Computational Framework for Design Optimization and 3D Printing of Prestressed Concrete Structures

9:30 AM – 9:50 AM

Author(s): Oded Amir, Technion - Israel Institute of Technology; Emad Shakur, Technion - Israel Institute of Technology

3D printing of cementitious materials has emerged as a promising technology for transforming the construction industry by reducing material waste, minimizing manual labor, and eliminating the need for conventional formwork through robotic fabrication. From a design perspective, it enables unprecedented geometric freedom, allowing the development of structurally optimized components with significant material savings compared to traditional construction methods. Nevertheless, practical limitations related to early-age material behavior and the geometry of the toolpath itself hinder the direct realization of optimized designs, and addressing these challenges is a central focus of our research.

Building on our recent work on optimizing three-dimensional prestressed concrete beams and slabs, we develop a shape-optimization-based computational framework to realize these designs by partitioning structures into 3D-printed and cast components, with the printed parts serving as formwork. The approach includes segmentation into printable units and the generation of buildable toolpaths that respect prestressing cable geometry. Buildability is ensured by incorporating material mix properties and robotic fabrication parameters, resulting in an integrated framework that links structural form, material behavior, and robotic fabrication.

To further extend the framework and enable topological optimization of the 3D-printed concrete layers, we develop a hybrid formulation that combines a continuous density field with a skeletal representation to optimize printing toolpath topology without relying on casting as a filling material. The method addresses key geometric challenges to ensure numerically robust, fully printable, continuous, and non-overlapping toolpaths, while accounting for prestressing integration and incorporating buildability constraints related to early-age concrete behavior. The resulting optimized designs constitute an additional step toward bridging optimization procedures with the practical fabrication of 3D-printed concrete structures.

Speaker



Oded Amir

Prof. | Technion - Israel Institute of Technology

ID 989: Combinatorial optimization of tall building aerodynamics using cyber-physical wind tunnel testing

9:50 AM – 10:10 AM

Author(s): Wei-Ting Lu, National Sun Yat-sen University; Brian Phillips, University of Florida; Zhaoshuo Jiang, San Francisco State University

Aerodynamic shape modification is a cost-effective method to reduce structural loads and improve occupant comfort for tall buildings. These shapes can be parametrized and formulated as an optimization problem to efficiently explore many candidate designs and to converge on the best solution for a given objective function and constraints. Continuous optimization problems have been explored for aerodynamic shape modification using both computational fluid dynamics (CFD) and boundary-layer wind tunnel testing (BLWT) to evaluate the candidate designs. However, combinatorial aerodynamic shape optimization problems have received little attention. As an example application, a tall building split into c layers along the height with n options for each layer is well-suited for combinatorial optimization. To explore the resulting discrete design space of time complexity cn , efficient search algorithms and rapid methods to evaluate candidate designs are required.

This study formulates aerodynamic shape optimization for tall buildings as a combinatorial problem, creating a massive and varied design space. To address the large time complexity and the discrete nature of the design space, a divide-and-conquer optimization algorithm is proposed. The algorithm uses element division to start with a simpler design space that can be more exhaustively explored before iteratively increasing the time complexity. Additionally, the algorithm uses a bit flipping/cycling approach to map adjacent solutions in the discrete design space. To address the need for rapid evaluation of candidate designs, a cyber-physical approach using BLWT testing is proposed. This approach uses a reconfigurable multi-section model to rapidly create candidate designs. These models are then immediately evaluated using high-frequency force-balance (HFFB) wind tunnel testing. The divide-and-conquer optimization algorithm, reconfigurable models, and BLWT testing make up the proposed cyber-physical approach to combinatorial aerodynamic shape optimization.

To demonstrate the convergence and robustness of the proposed shape optimization approach, three combinatorial case studies were investigated. Cyber-physical optimization was conducted at the University of Florida's (UF) BLWT, an NSF-sponsored Natural Hazard Engineering Research Infrastructure (NHERI) Experimental Facility. Through the three case studies, a total of 191 models were tested in 10 normal working days. In comparison with a benchmark model, the objective function (i.e., standard deviation across-wind base moment) of the best performing models was reduced by around 48%, outperforming more traditional aerodynamic strategies. Beyond the optimal designs, the large experimental database provides insights into impact of various cross-sections sequences and patterns along the height of tall buildings.

Speaker



Brian Phillips

Professor | University of Florida

ID 762: Residual-Stress–Driven Response Spectrum Optimization of Lightweight Structures Subject to Impact

10:10 AM – 10:30 AM

Author(s): Paul T. Kühner, University of Luxembourg; Michal Habera, University of Luxembourg; Andreas Zilian, University of Luxembourg

Carbon fiber–reinforced polymers (CFRPs) enable lightweight, high-performance structural designs with a high degree of sparsity. Such sparsity accentuates the intrinsic complexity of the structural response, leading to a challenging mechanical behavior landscape. We present a computational model for an additively manufactured, filament-wound CFRP truss structure consisting of discrete connection points (“anchors”) and one-dimensional members (“strings”). The anchors are attached to a shielding surface subject to blast impact. Owing to the pronounced stiffness contrast, the anchors are modeled as rigid bodies interconnected by one-dimensional string elements.

The constitutive behavior of the strings is described using a geometrically nonlinear (finite-deformation), bimodular elastic material model. This analytical framework yields a continuous representation of the strain energy, derived using Tangential Differential Calculus (TDC).

Ensuring elastic behavior about a prescribed residual stress state is of particular importance for the design of structures subjected to non-proportional and uncertain loading. Optimization with respect to complementary residual stress states and maximum admissible load factors leads to generally constrained optimization problems. In this contribution, we present shape optimization strategies for CFRP truss structures designed for a resilient response spectrum under impact loading.

We formulate the problem as an optimal control problem, expressed in terms of residual stresses and the optimization of the structural response spectrum. An efficient numerical implementation and algorithmic framework are developed based on an adjoint formulation. The proposed methodology is demonstrated using real-world engineering case studies, highlighting both its effectiveness and its computational efficiency in practical applications.

Speaker



Andreas Zilian

University of Luxembourg

ID 786: Realistic optimality: Printability constrained truss optimization for 3d printed concrete

10:30 AM – 10:50 AM

Author(s): Hajin Kim-Tackowiak, MIT; Zane Schemmer, MIT; Josephine Carstensen, MIT

Formwork for concrete accounts for up to half of total construction costs and time. While not a fix-all for this labor and material intensive process, Concrete 3D Printing (C3DP) has seen an uptick in interest to help reduce this impact. Meanwhile, the coupling of additive manufacturing and high-precision computational design tools have enabled the fabrication of increasingly high-performance structural forms. However, large-scale extrusion-based additive manufacturing systems, like C3DP, remain highly constrained by machine-specific limitations. These physical constraints are rarely accounted for during the design process. Instead, current workflows often rely on extensive post-processing to generate printable optimized geometries. This increases the cost and limits the applicability of large-scale additive manufacturing. This work seeks to implement printability constraints directly into a topology optimization scheme in order to reduce, and eventually eliminate, the need for post-processing.

In order to define printability, the following C3DP-specific constraints are addressed: discrete deposition widths, minimum turning angles, and continuous tool-paths per layer. Each of these constraints is defined and enforced within the optimization problem formulation. To define the boundaries of the constraints, physical measurements are taken from process-parameter testing on a custom built C3DP gantry system.

This work addresses printability by directly incorporating the aforementioned constraints into the structural optimization process. Mixed-integer nonlinear programming (MINLP) is used within a truss-based topology optimization (TO) framework to generate readily printable designs. The produced results are materially efficient at very low volume fractions and inherently compatible with large-scale extrusion-based fabrication. Building on prior work demonstrating the robustness of MINLP-based TO at low densities, this approach shifts the optimization target from purely structural performance toward optimal and printable geometries. While objective performance is sacrificed on paper, the new designs are functionally more optimal due to their printability.

The proposed workflow translates optimization outputs directly into fabrication-ready toolpaths with minimal post-processing. To demonstrate feasibility, a compression-only concrete specimen is designed, printed, and experimentally tested. The results illustrate how embedding constructability constraints within the design stage enables a smooth transition from computational design to physical realization, supporting scalable deployment of extrusion-based additive manufacturing in construction.

Speaker



Hajin Kim-Tackowiak

PhD | MIT

ID 796: Challenging Traditional Column Layouts in Buildings with Structural Optimization

10:50 AM – 11:10 AM

Author(s): Yakov Zelickman, Johns Hopkins university; Oded Amir, Technion - Israel Institute of Technology

Column layout is a fundamental design decision in building structures and has a significant impact on structural efficiency. Traditionally, column layouts are determined early in the design process by architects to satisfy architectural requirements. In subsequent stages, structural engineers refine these layouts, typically seeking minimal deviation from the architectural design while adhering to prescribed architectural constraints, often defined as allowable regions for column placement.

In this study, we apply our previously developed stiffness projection method to optimize column locations while explicitly incorporating architectural constraints. Our results demonstrate that conventional column layouts are often far from optimal and that the corresponding optimal configurations can be non-intuitive. At the same time, we show that most of the achievable improvement in structural performance can be attained through relatively small modifications to traditional designs. Given the strong influence of column layout on structural performance, these findings highlight the substantial potential of structural optimization methods to enhance building efficiency without requiring major architectural compromises.

Speaker



Yakov Zelickman

Dr. | Johns Hopkins University

MS 091: Advances in Modeling of Material Damage and Fracture

9:30 AM – 11:30 AM | Location: KTCH 1B87

Chair(s): Mostafa Mobasher; Lampros Svolos; Aditya Kumar; Georgios Moutsanidis; Alessandro Fascetti; Ravindra Duddu; Haim Waisman

Moderatorss



George Moutsanidis

Assistant Professor | Rutgers University



Ravindra Duddu

Associate Professor | Vanderbilt University

ID 818: Lattice discrete particle model for reinforced concrete structures: A novel geometrically consistent approach

9:30 AM – 9:50 AM

Author(s): Yingbo Zhu, Johns Hopkins University; Dongge Jia, University of Pittsburgh; John Brigham, University of Pittsburgh; Alessandro Fascetti, University of Central Florida

The interaction between steel and concrete is critical in the performance of Reinforced Concrete (RC) structures. Yet, the complexity of bond-slip behavior and the heterogeneous nature of concrete creates challenges for accurately predicting fracture behavior, particularly in the simulation of failure patterns. In this context, novel modifications to the Lattice Discrete Particle Model (LDPM) are proposed herein for simulating RC structures, with a particular focus on the bond-slip behavior governing the rebar-concrete interactions. A new geometrically consistent strategy is proposed to materialize steel rebar in the simulations, enabling the realistic definition of bond elements within the LDPM framework. A bond stress-strain constitutive law and a compressive behavior model for bond elements within the LDPM framework are presented. Additionally, to realistically simulate radial stresses due to rib-induced dilation, the introduction of a local rotation angle is proposed. The derived LDPM framework is extensively validated through comparisons with experimental results from pull-out tests on unconfined and confined cylinders, as well as flexural bending tests on RC beams with lap splices. The approach is shown to accurately capture important mechanical behaviors in different types of RC elements, including load-displacement responses, cracking patterns, failure mechanisms, and bond-slip behavior at the steel-concrete interface. Further validation is shown for RC beams with varying reinforcement layouts under four-point bending loads, revealing that the proposed approach can be applicable to large-scale RC structures with varying reinforcement configurations.

Speaker



John Brigham

Professor | University of Pittsburgh

ID 978: A Finite-Strain Microplane Damage Model for Fracture of Soft Materials

9:50 AM – 10:10 AM

Author(s): Anh T Nguyen, Northwestern University; Yang Zhao, Northwestern University; Zdenek Bazant, Northwestern University

Fracture in soft materials such as elastomers and biological tissues is traditionally characterized by a constant fracture energy, independent of non-singular stresses. Recent advances in the fracture of stiff quasi-brittle and ductile solids have revealed, however, that non-singular crack-parallel stresses can significantly influence fracture resistance, leading to a fracture energy that varies with loading state. These findings suggest that fracture cannot be fully described by a purely singular crack-tip field and that a finite-width damage zone must exist at the fracture front.

Here, the study of the effect of crack-parallel stresses on fracture behavior is extended to soft materials undergoing large strain. Modified gap tests are conducted on synthetic rubber under controlled crack-parallel pre-compression. The experiments show that increasing crack-parallel compression produces an increase in both peak load and measured fracture energy. Complementary cutting tests confirm enhanced energy dissipation under compressive crack-parallel compression, demonstrating that the observed effect is intrinsic to the fracture process and not an artifact of boundary conditions. These results provide evidence that fracture in soft materials cannot be described solely by a constant fracture energy and a line crack model. Instead, the data implies the existence of a finite-width damage zone at the fracture front whose development is strongly affected by non-singular stresses. These findings challenge conventional hyperelastic fracture formulations and motivate the need for incremental inelastic modeling capable of capturing damage evolution under finite strains.

To explain and verify these observations, a finite-strain microplane damage model is developed by extending an existing thermodynamically consistent microplane framework for hyperelasticity. In this approach, the macroscopic free energy is obtained as an integral of microplane energies over all orientations, and large-strain kinematics are described using microplane stretch and distortion measures. Damage is introduced through orientation-dependent degradation of the microplane energy, enabling progressive stiffness loss and strain localization within a finite damage zone. The model naturally captures load-induced anisotropy and the coupling between crack-parallel stress and fracture resistance without invoking ad hoc stress-dependent fracture criteria. Finite element simulations reproduce the experimentally observed increase in peak load and fracture energy under pre-compression, confirming that the crack-parallel stress effect arises from the evolution of a finite-width damage zone rather than from singular crack-tip mechanics. The proposed framework provides a physics-based foundation for modeling fracture of soft materials under multiaxial loading and offers a bridge between hyperelasticity and damage mechanics at finite strain.

Speaker



Anh Nguyen

Research Assistant | Northwestern University

ID 995: Crack-Parallel Stress Effects in Fracture of Knitted Soft Composites

10:10 AM – 10:30 AM

Author(s): Xiaoxiao Ding, Department of Mechanical Engineering, Northwestern University; Yanzhao Niu, Department of Civil Engineering, Northwestern University; Yang Zhao, Department of Civil Engineering, Northwestern University; Zdeněk Bažant, Department of Civil, Mechanical, and Material Science and Engineering, Northwestern University; Jian Cao, Department of Mechanical Engineering, Northwestern University

Knitted textiles are increasingly used in soft robotics and wearable devices because their looped geometry can rotate, redistribute load, and resist damage. In service, these textiles undergo multiaxial loading and geometric constraints, so cracks propagate under mixed stress states with non-negligible crack-parallel stress. In anisotropic knitted architectures, such tangential loading can promote yarn sliding and bridging and can change crack-growth stability in ways not captured by classical LEFM.

We propose a microplane triad damage model for dry cotton knitted fabrics and generalize it to PDMS-embedded configurations via volumetric homogenization of the fabric–matrix composite response. The model represents anisotropic deformation and progressive degradation through an ensemble of oriented microplane triads along the yarn that encode yarn-dominated mechanisms while allowing confinement effects from the surrounding matrix. This provides a unified description across fabric topology and embedding conditions. A key capability is capturing how crack-parallel stress controls the onset and trajectory of damage localization, as well as the peak-load response, reproducing experimentally observed sensitivity of crack initiation and growth to multiaxial loading.

The framework is implemented in Abaqus/Explicit through a user material subroutine and validated using tension gap tests, which enable systematic control of crack-parallel stress levels. The proposed approach offers a mechanistic, design-oriented tool to predict fracture of knitted-fabric soft composites under realistic loading states and to guide architected textile selection for improved damage tolerance.

Speaker



Yanzhao Niu

PhD student | Northwestern University

ID 694: Predicting ductile fracture in additively manufactured hot isostatically pressed stainless steel 316L

10:30 AM – 10:50 AM

Author(s): Surajit Dey, Arizona State University; Subramaniam Rajan, Arizona State University; Ravi Kiran, Arizona State University

The ductile fracture behavior of additively manufactured (AM) and hot-isostatically pressed (HIP) stainless steel 316L is investigated using a combined experimental and numerical approach. Existing studies on fracture in AM metals primarily rely on specimens extracted from bulk AM blocks, and a stress-state-dependent fracture locus for HIP-treated AM SS316L has not yet been established. The present study addresses this research gap by characterizing ductile fracture in HIP-treated AM SS316L using specimens directly printed in their final geometries and designed to span a wide range of stress states.

A set of plate-shaped and notched cylindrical specimens was designed to generate shear-dominated, combined shear-tension, and tension-dominated stress states when subjected to quasi-static uniaxial tensile loading. All specimens were fabricated using laser powder bed fusion (LPBF) with SS316L powder and subsequently subjected to hot isostatic pressing to reduce porosity and homogenize the microstructure. Mechanical testing was conducted under displacement-controlled quasi-static uniaxial tension, and full-field strain measurements were obtained using three-dimensional digital image correlation (DIC). Finite element simulations using isotropic J2 plasticity were performed to simulate the experimental load-displacement response and to extract strain-averaged stress triaxiality and equivalent plastic strain at fracture from elements located near the experimentally identified fracture initiation locations.

Using data obtained from multiple specimen geometries, a fracture locus was constructed relating strain-averaged stress triaxiality to equivalent plastic strain at fracture. Closed-form analytical expressions describing the fracture locus were developed using a data-driven approach, enabling an interpretable and computationally efficient representation of the fracture locus. In addition, a stress-state- and plastic-strain-dependent material-softening formulation was introduced to account for material softening in the fracture model. The proposed framework provides a systematic approach for characterizing and modeling ductile fracture across a broad range of stress states. The resulting fracture model accurately predicted the fracture displacement and the location of ductile fracture initiation in HIP-treated AM SS316L specimens.

Speaker



Ravi Kiran Yellavajjala

Associate Professor | Arizona State University

ID 219: Multiscale Modeling of the Elastic Modulus of Recycled Aggregate Concrete

10:50 AM – 11:10 AM

Author(s): Osamah Dehwah, National Institute of Standards and Technology || Johns Hopkins University; Stephanie Watson, National Institute of Standards and Technology

The heterogeneous and multiscale nature of concrete makes accurate prediction of its mechanical behavior challenging, particularly when recycled aggregates are used. The use of recycled aggregate concrete (RAC) has gained increasing attention due to resource scarcity and environmental concerns; however, the presence of residual mortar, microcracks, and complex phase interactions significantly complicates theoretical modeling. Most existing theoretical models simplify RAC as a two-phase composite of mortar and aggregate and commonly neglect the role of cement paste, hydration products, and Poisson's ratio.

This study presents a multiscale, multiphase micromechanical framework for predicting the elastic modulus of RAC. The proposed model integrates microscale and mesoscale interactions using homogenization theory, combining the Mori-Tanaka and Generalized Self-Consistent (GSC) schemes. At the microscale, the cement matrix comprising clinker phases and hydration products, is modeled explicitly accounting for phase morphology and Poisson's ratio. At higher length scales, sand and aggregates are incorporated through the GSC model to represent mortar and concrete behavior.

The framework was validated in two stages. In the first stage, elastic moduli of concrete comprised of natural aggregate and recycled aggregate were predicted independently and showed errors below 10% compared with experimental data. In the second stage, model predictions exhibited good agreement with reported experimental results for RAC. The results demonstrate that Poisson's ratio has a non-negligible influence on elastic modulus predictions and should be explicitly included in theoretical formulations. The proposed framework provides a flexible and extensible computational tool for multiscale modeling of heterogeneous concrete materials and can be further refined as additional mechanical data related to interfacial transition zone (ITZ) become available.

Speaker



Osamah Dehwah

NIST | JHU

ID 975: Cohesive Zone Modeling of Mode-II Interfacial Fracture in Cementitious Repairs

11:10 AM – 11:30 AM

Author(s): Ayumi Manawadu, University of South Florida; Pizhong Qiao, Shanghai Jiao Tong University

Shotcrete overlays are commonly employed to repair deteriorated overhead and vertical concrete surfaces. The material mismatch between the existing concrete substrate and the newly applied overlay results in a weak bi-material interface that is highly susceptible to damage. This interface is frequently subjected to dominant shear-type loading and may significantly affect the overall performance of the repaired structure.

This study conducts a mechanics-based numerical investigation of Mode II fracture behavior in shotcrete–concrete interfaces. Interfacial debonding and fracture are modeled using a cohesive zone model, while the nonlinear cracking and inelastic behavior of both the substrate and the overlay are modeled using a concrete damage plasticity model. The numerical study is validated using Mode II fracture experiments.

A parametric study is conducted to quantify the influence of cohesive strength and critical fracture energy on interfacial failure mechanisms. The results indicate that these parameters control the transition from adhesive debonding at the interface to cohesive cracking within the cementitious materials. As both properties are significantly influenced by substrate surface preparation, the findings highlight the need for fracture-based interface testing and cohesive zone modeling, alongside conventional bond-strength tests, for reliable design and durability assessment of concrete repair systems.

Speaker



Ayumi Manawadu

Assistant Professor | University of South Florida

MS 062: Analysis of Heritage Structures: Tools and Methods for Assessing Historic Monuments and Structures

9:30 AM – 11:30 AM | Location: GUGG 205

Chair(s): Rebecca Napolitano; Linda Seymore; Branko Glisic; Admir Masic; Daniele Paulino

Moderators



Daniele Paulino

Structural Engineer | TYLin

ID 345: Case studies in landmark office-to-residential conversions in the United States

9:30 AM – 9:50 AM

Author(s): Roman Shipley, Northeastern University; Demi Fang, Northeastern University

The demand for office space has uniquely declined in the United States in recent decades. In several cities, this includes tall, historic landmark structures that face obsolescence. Attempts to convert these former office spaces to residential spaces have had mixed success. This presentation will summarize the quantitative and qualitative details of twelve successful, ongoing, and unsuccessful conversions of landmark office buildings to residential buildings in the United States. Of the twelve buildings, four are successful conversions, seven are ongoing or stalled, and one has an uncertain future. The buildings range from 165 to 1080 feet in height, and all but one were originally constructed before 1940. Given their size and historic status, the success of their conversions has a nontrivial impact on the urban landscape from both dimensions of preservation and sustainability.

Our presented work will summarize quantitative statistics across these twelve case studies, such as conversion cost per square footage, per story, and per height. Where possible, material quantities of a few case studies will also be estimated to demonstrate carbon emission savings possible through a successful conversion relative to new construction of a similar building.

These quantitative data will be complemented by qualitative details on each building, such as the heritage status of each building and other documented narratives about success factors or barriers. Our research thus far demonstrates that policy and public perception play an important role in the success of conversions, which are social dimensions that uniquely overlap with the architectural and engineering considerations of conversion.

Taken together, these quantitative and qualitative insights on several key office-to-residential conversions of historic buildings. These findings will help stakeholders anticipate success factors and barriers to high-stakes conversions that can transform the preservation and sustainability performance of cities. Furthermore, the narratives that emerge from this work will be foundational to future work where similar conversions are anticipated elsewhere in the United States based on their lifetimes and vacancy rates.

Speaker



Roman Shipley

Student Research Assistant | Northeastern University

ID 358: Machine Learning Analysis of Historic Building Vulnerability to Tornado Damage: A Multi-Model Framework for Preservation Planning

9:50 AM – 10:10 AM

Author(s): Saanchi Kaushal, Penn State; Yishuang Wang, Penn State; Mariant Gutierrez Soto, Penn State; Rebecca Napolitano, Penn State

While considerable research examines wind loading on modern structures, empirical evidence linking specific structural features to tornado performance in historic buildings remains limited. Preservation professionals currently rely on anecdotal observations or generalized wind engineering principles that may not capture the complex failure mechanisms characteristic of aged construction. This knowledge gap poses significant challenges for historic downtown districts—often serving as economic and cultural anchors—which face mounting exposure to intensifying tornado activity yet lack evidence-based retrofit guidance.

This research analyzes historic buildings from the 2020 Nashville and 2021 Quad State tornadoes to identify which observable characteristics differentiate structures that survive from those experiencing significant damage. To extract reliable findings from limited data, we implement a multi-model machine learning framework benchmarking six algorithms through statistical equivalence testing, ensuring that identified vulnerabilities replicate across analytical approaches rather than reflecting single-model artifacts.

The findings advance historic preservation practice by establishing a hypothesis-generating framework that prioritizes targets for future validation through wind tunnel testing, finite element modeling, and cost-benefit analysis. These outcomes underscore the necessity of physics-based simulation to confirm identified vulnerability factors and translate data-driven insights into minimally invasive, reversible interventions compatible with the Secretary of the Interior's Standards. Such efforts enable preservation authorities to allocate limited resources toward targeted strengthening strategies that reduce catastrophic loss while maintaining architectural integrity.

Speaker



Rebecca Napolitano

Assistant Professor | Penn State

ID 542: Structural classification and identification of historical timber barn frames

10:10 AM – 10:30 AM

Author(s): Moriah Hughes, Princeton University; Branko Glisic, Princeton University

Historical timber barns are a vast population of heritage structures. Constructed throughout the 18th-20th century across the United States, barns were individually adapted to regional material sources or availability and local agricultural needs and farming practices. They were also influenced by traditions of timber frame and barn construction from ethnic or cultural groups or barn builders, and by changing agricultural technology. Later, their form and structure were influenced by the spread of more scientific approaches to structural design and agricultural production.

The interaction of these many influences resulted in a vast variety of barn forms. Although the work of cultural geographers and historians has resulted in the coherent definition of some specific barn types based on functional, architectural, and sometimes constructional features, no comprehensive classification has been created for this building population, particularly one that creates a clear categorization of form and behavior.

A comprehensive and structurally-enlightening classification of barns is only increasingly necessary, as urbanization and threats to smallholder farming only increase the rate of loss of these heritage buildings. In addition, their increasing age and often deteriorating condition make them increasingly vulnerable to structural demands like settlement and extreme wind events. Structural definition is needed to allow owners, restorers, and preservation organizations to properly document their buildings and to allow systematic structural study of the population that can facilitate better decision-making for their maintenance and preservation.

Consequently, this work creates a comprehensive structural classification for the Midwestern barn population which gives specificity to structural form and behavior. The classification was based on a dataset gathered from historical building records, contemporary literature sources, and past scholarly studies. After analyzing the population, frame lateral stability mechanism was selected as the classifying feature. This approach yielded eight fundamental structural types, and various hybrids of the fundamental types.

For the fundamental types, the critical load-bearing elements are identified under key loading scenarios. From these results, key structural vulnerabilities under deterioration agents and loading events are identified and some possible interventions discussed, also by type.

Finally, structural analysis was performed on selected examples from the dataset in order to determine global lateral structural stiffness. A material efficiency parameter was derived which expressed the material utilization normalized by frame section area. Plotting these two variables, stiffness and material efficiency, allowed an objective categorization of frame types and yielded insights into changes in design and construction approaches across time and types.

The definition of a rigorous, comprehensive classification that corresponds to distinctives in structural behavior and load path thus allows for rigorous, consistent documentation of these heritage buildings, and also allows the identification of key structural vulnerabilities of each major type. This work therefore provides insights into maintenance, repair, and retrofit strategies for these historical buildings, so that owners, who often alter, upkeep, or repair these buildings themselves, as well as restorers or preservation entities can make more informed and maximally beneficial decisions.

Speaker



Moriah Hughes

PhD Candidate | Princeton University

ID 598: Data Integration and Visualization for Damage Assessment of Historic Masonry Walls

10:30 AM – 10:50 AM

Author(s): Daniele Paulino, TYLin; Anna Blyth, TYLin; Margaret Cowie, TYLin

The assessment of historic masonry structures increasingly relies on the integration of heterogeneous diagnostic data, including onsite inspections, non-destructive evaluation (NDE), and three-dimensional documentation. In practice, these datasets are often produced in isolation, vary significantly in scale and format, and are difficult to interpret collectively within a spatial and structural context. This presentation will present a study focused on a historically sensitive rubble stone masonry structure where limitations in ground-penetrating radar (GPR) coverage required the integration of complementary diagnostic methods. The study is used as a precedent for implementing a data-driven workflow that supports the compilation and visualization of multiple assessment datasets, integrating borescope inspection data, ground-penetrating radar (GPR) void detection, and photogrammetry-based geometric models within a unified three-dimensional framework to support engineering evaluation of historic masonry walls. Raw datasets are processed, spatially aligned, and segmented into discrete wall regions corresponding to architectural sections and changes in wall geometry. A python custom script is developed to enable visualization of these different datasets, allowing users to evaluate localized wall conditions without requiring advanced modeling expertise. The resulting framework supports both qualitative interpretation and quantitative analysis, facilitating clearer communication between engineers, conservators, and project stakeholders. By pairing less precise inspection data, such as borescope information, with higher resolution but spatially limited NDE results, the workflow enables extrapolation of existing conditions, more accurate identification of damage extents, and improved development of compatible repair strategies and quantity estimates. While presented as a case study, the methodology is intended as a transferable precedent for integrating multi-modal assessment data in the evaluation of historic masonry structures.

Speaker



Daniele Paulino

Structural Engineer | TYLin

ID 1016: Cultural heritage protection: shaping the future

10:50 AM – 11:10 AM

Author(s): Antonina Pirrotta, UNIVERSITY OF PALERMO; Chiara Masnata, UNIVERSITY OF PALERMO

CULTURAL HERITAGE PROTECTION: shaping the future

Isolation system is very effective control device for protecting buildings under earthquake, however the common way of using this device is not proper for cultural heritage.

Consider other devices that generally mitigate the vibration of the top of structure, I am thinking the control of control.

So these devices are considered to control the base isolators displacements. Since I would like to not consider huge mass for this devices I will introduce a novel device called Sliding Tuned Liquid Column Damper.

Experimental results in good agreement with numerical results assess the validity of this device.

Speaker



Antonina Pirrotta

Professor PhD | University of Palermo

ID 1043 Assessing Historic Masonry on the University of Colorado Boulder Campus

11:10 AM – 11:30 AM

Author(s): Peter Babaian, Senior Principal, Simpson Gumpertz & Heger; Christopher Sachs, Assistant Dean for Operations, Facilities, and Safety, University of Colorado Boulder

Old Main and Hale Science are two of the oldest buildings on the CU Boulder campus. A 2019 exterior condition assessment determined that both buildings required significant exterior masonry restoration. A finite element analysis of Old Main showed structural stress distribution and how inputting observed deterioration into the model predicted areas of cracking that matched observations on the building. For Hale Science, the analysis was more straightforward. The stone structure comprising the grand entry stair on the north elevation, supporting three stories of building above, was severely deteriorated, potentially compromising the structural stability over the long term. As a result of both of these analyses, Old Main recently received a full exterior restoration and Hale Science is in the process of reconstructing the grand entry stair while the building above is temporarily shored. This presentation will give an overview of the analyses of each project and talk about the recommendations resulting from each, as well as information regarding the reconstruction of the Hale Science grand entry stair (for which the presenter is SER). A tour of the buildings will also be held as part of the conference.

Speaker



Peter Babaian

Senior Principal | Simpson Gumpertz & Heger

Ms 063: Advanced Spatiotemporal Modeling and Risk Assessment of Natural Hazards for Resilient Infrastructure Systems

9:30 AM – 11:30 AM | Location: ECON 119

Chair(s): Abdollah Shafieezadeh; Yue Li; Hanbyeol Shin

Moderatorss



Yue Li

Professor | Case Western Reserve University



Hanbyeol Shin

PhD Candidate | The Ohio State University

ID 340: Generative Spatiotemporal Modeling of Extreme Wind Fields for Network-Level Infrastructure Resilience Analysis

9:30 AM – 9:50 AM

Author(s): Hanbyeol Shin, The Ohio State University; Abdollah Shafieezadeh, The Ohio State University

Assessing the resilience of critical infrastructure, particularly for spatially distributed systems such as power networks, requires stochastic realizations of environmental hazards that preserve physical realism. Current resilience analysis practices often rely on code-based probabilistic tools (e.g., ASCE 7 hazard tool) to derive Mean Recurrence Intervals (MRI) and corresponding scalar hazard intensities. While sufficient for site-specific design, these point-based methods fail to capture the temporal evolution and the spatial structure and correlations of extreme weather events. Recent studies have explored data-driven approaches, such as Generative Adversarial Networks (GANs), to synthesize spatial hazard fields. However, these adversarial methods often struggle to fully capture the diverse tail statistics of extreme distributions needed for robust reliability assessment. Consequently, for large-scale networks, inadequate representation of these coherent spatiotemporal structures can lead to biased estimates in system risk and resilience metrics that depend on joint exceedance of component wind demands, e.g., correlated damage states, multi-component outage initiation, and cascade propagation.

To address this limitation, this study proposes a conditional deep learning-based generative framework designed to synthesize high-resolution, spatiotemporal wind scenarios. Unlike traditional statistical methods that generate spatially unstructured intensity inputs from simplified correlation matrices, and improving upon recent adversarial approaches that struggle with temporal coherence, the proposed model learns the high-dimensional joint probability distribution of wind fields directly from high-fidelity meteorological data. The framework is “conditional,” allowing users to specify key intensity metrics (e.g., MRI-consistent wind speeds, storm duration) while the model stochastically generates an ensemble of physically consistent spatiotemporal realizations that satisfy those conditions.

The application of this framework is demonstrated through a resilience analysis of a regional power grid. By fixing the hazard intensity condition and generating a diverse ensemble of potential storm tracks and footprints, we perform a probabilistic impact assessment that accounts for the aleatoric uncertainty of the hazard’s spatial topology and the induced spatial dependence of component demands. This approach quantifies the variance in system-level performance, such as the distribution of customer outages and component failures, for a single design-level event. The results highlight that the wind-field footprint and associated dependence structure is a critical driver of grid failure, moving resilience analysis beyond static, worst-case assumptions toward rigorous, scenario-based uncertainty quantification.

Speaker



Hanbyeol Shin

PhD Candidate | The Ohio State University

ID 350: On the Applicability of Risk-Targeted Seismic Criteria to Existing Bridges

9:50 AM – 10:10 AM

Author(s): Shaymaa Obayes, University of Delaware; Monique Head, University of Delaware

Risk-targeted seismic design approaches have been developed to control collapse risk in newly designed bridges; however, the applicability of these criteria to existing bridges designed under older codes is less studied and may reveal demands that bridges were not designed for. This study evaluates the collapse risk of pre-1990 multi-span precast concrete girder (MSPCG) and slab bridges in the Pacific Northwest using risk-targeted ground motions adopted in the 2023 AASHTO LRFD Bridge Design Specifications, with explicit consideration of long-duration moment magnitude (MW) 9.0 Cascadia Subduction Zone earthquakes. Nonlinear time-history analyses and fragility assessments are conducted to quantify incipient collapse risk for representative legacy bridge configurations. Results indicate that explicit inclusion of long-duration MW 9.0 ground motions leads to a substantial increase in estimated collapse risk, exceeding the target 1.5% probability of collapse in 75 years. While risk-targeted spectra can achieve this target for new bridge designs through displacement adjustment factors, such modifications do not apply to existing bridges, highlighting the necessity of retrofit interventions. Overall, the findings indicate that while risk-targeted design criteria effectively control collapse risk for new bridges, their extension to existing bridges requires dedicated evaluation frameworks to quantify seismic performance and inform retrofit decisions under long-duration earthquakes.

Speaker



Shaymaa Obayes

Research Assistant | University of Delaware

ID 389: Probabilistic Seismic Risk Assessment of Interdependent Utility Systems for Functional Recovery

10:10 AM – 10:30 AM

Author(s): Shuochuan Meng, Arup US, Inc; Laxman Dahal, Arup US, Inc; Mike Mieler, Arup US, Inc

Reliable operation of utility infrastructure is essential to the resilience of communities following major earthquakes. While seismic risk assessments often focus on individual assets, system-level performance is frequently governed by spatially distributed damage, interdependencies, and cascading failures across interconnected networks. This study presents a probabilistic, component-level seismic risk assessment framework applied to a complex, campus-scale utility system comprising potable water, wastewater, and electrical power networks.

The proposed framework couples probabilistic seismic hazard characterization with component-level damage fragilities, fault-tree-based system logic, and recovery analysis to evaluate functional performance of interconnected utility networks. Spatially variable ground shaking and liquefaction-induced ground deformation are represented through probabilistic intensity measures sampled via Monte Carlo simulation. Component damage is estimated using hazard-specific fragility relationships for structural, equipment, and buried lifeline elements. System functionality is evaluated using fault-tree-based logic that explicitly captures single points of failure, redundancies, and interdependencies within and across utility systems. The assessment considers vulnerabilities associated with both off-site municipal supply systems and on-site utility infrastructure, including their interdependencies and relative contribution to system-level service disruption. Post-event recovery is simulated by incorporating repair sequencing, labor constraints, mobilization delays, and equipment procurement lead times, enabling estimation of service restoration trajectories under uncertainty. Based on the assessment results, targeted mitigation strategies, including both physical and operational measures, are developed and incorporated into the system model, and the assessment is repeated to generate updated recovery trajectories and quantify avoided downtime attributable to the mitigations. The methodology produces system-level performance metrics, including service availability and time to recovery, across multiple seismic return periods.

Results indicate that system-level outage and recovery trajectories are often controlled by network configuration, single points of failure, and cross-sector dependencies rather than by peak structural damage alone. The assessment results further illustrate pronounced spatial variability in utility service disruption across the network, as well as significant variation in recovery trajectories among affected service areas. In particular, buried lifeline components and power-dependent facilities play a dominant role in driving prolonged service disruptions, even under moderate seismic intensity levels. The analysis further demonstrates how targeted mitigation strategies and operational planning can substantially reduce downtime without requiring wholesale system replacement.

The proposed methodology provides a transferable decision-support tool for evaluating the seismic resilience of interdependent utility systems and supports risk-informed prioritization of mitigation and recovery planning, effectively bridging the gap between advanced probabilistic modeling and practical engineering decision-making. This work contributes to advancing probabilistic, system-level approaches for infrastructure resilience assessment and functional recovery.

Speaker



Shuochuan Meng

Risk and Resilience Engineer | Arup

ID 497: Severe convective storm wind and hail compound fragility assessment of low-rise structures

10:30 AM – 10:50 AM

Author(s): Andres Calvo, Rice University; Jamie Padgett, Rice University; Guirong Yan, Missouri University of Science and Technology

Severe convective storms (SCS) are extreme weather events characterized by high-speed winds, rainfall and large hail (i.e., diameter greater than 1 in). In recent years, SCS have been responsible for multimillion-dollar losses and insurance claims, primarily in the Great Plains and the South-Central states of the US. Hailstorms alone can result in extensive damage to the low-rise buildings' envelope components, including the roof and siding. The damage can be exacerbated by the high-speed winds in SCSs, which modify the velocity and impact direction of individual hailstones. Thus, the compound action of wind (pressure) and hail (impacting force) can result in major economic loss for the impacted region. Nevertheless, there is a lack of studies on the physical damage posed by hailstorms during SCS events to the built environment, and in particular, the combined damage induced by wind and hail in a SCS. Therefore, the present research aims to develop a fragility assessment framework for the envelope components of low-rise structures (e.g., residential, commercial, and industrial buildings) under the combined loads exerted by hail and wind.

A hail hazard and demand model is proposed to simulate stochastically hailstorms based on the hail size distribution spectrum and determine the kinetic energy of hailstones acting on roof and siding components. The individual hailstone properties are treated as random variables (e.g., density, drag coefficient). Wind pressure distribution and the related statistical analysis are informed by wind tunnel databases. The kinetic energy and uplift pressure capacity for common building materials for roofs and siding are informed by experimental tests and damage assessment reports. Capacity models for functional failure probability are proposed for the different envelope systems (e.g., asphalt shingles, metal, single- and multi-ply roofs) considering the maximum kinetic energy impact for hail impacting and wind-induced pressure (i.e., lift pressure).

A Monte Carlo simulation (MCS) framework is employed to simulate multiple storm events with different characteristics (e.g., duration and direction). For each simulation, the quantity of damaged envelope components is evaluated and classified in damage states based on the damage severity. Multiple building roof configurations are considered, including flat, gable and hip roofs. Additionally, different roof pitches and floor plan dimensions are also accounted for. Bivariate fragility surfaces for each damage state are informed conditioned on wind velocity (e.g., 10-m 3-s peak wind gust velocity) and maximum hail diameter as intensity measures. Furthermore, fragilities are parametrized on building geometries and envelope materials for common low-rise archetypes. The delivered fragility models can be used to better understand the SCS risk due to the combined wind and hail conditions. The models can be used by decision-makers, catastrophe modeling specialists, and insurance companies to estimate risk and inform mitigation actions and risk transfer strategies.

Speaker



Andres Calvo

Graduate Research Assistant | Rice University

ID 727: Spatially interpretable dimensionality reduction for storm surge analysis: a unified treatment to overcome missing data, model bias and high dimensionality

10:50 AM – 11:10 AM

Author(s): Xi Zhong, The Hong Kong University of Science and Technology; Jize Zhang, The Hong Kong University of Science and Technology

High-fidelity hydrodynamic models and sensor networks generate massive datasets essential for coastal risk assessment; however, these resources are frequently compromised by incompleteness (dry nodes), observation sparsity, and high dimensionality. Traditional reduction techniques, such as Principal Component Analysis (PCA), struggle to accommodate missing data and produce abstract global modes that lack physical interpretability. This study presents a novel data-driven framework based on Non-negative Matrix Factorization (NMF) to address these operational challenges in ocean engineering. Unlike global methods, NMF decomposes surge fields into additive, spatially localized patterns that align with physical sub-regions, allowing for the native handling of missing values without pre-imputation. We demonstrate the framework's utility through three engineering applications using the NACCS storm surge database. In imputation, we recover missing data in dry nodes with high accuracy; in bias correction, we significantly reduce model error by projecting sparse high-fidelity gauge data; in surrogate modeling, NMF aids to predict peak surges with accuracy comparable to PCA but with interpretable reduced dimensions. The results establish NMF as a reduction technique, but more beyond as a practical spatial-aware tool for coastal modelers to manage incomplete data and enhance the reliability of storm surge risk assessments.

Speaker



Jize Zhang

Assistant Professor | The Hong Kong University of Science and Technology

ID 939: Learning Boundary–Interior Coupling for Compound Flood Forecasting Using Graph Neural Networks

11:10 AM – 11:30 AM

Author(s): Zanko Zandsalimi, University of Virginia; Mehdi Taghizadeh, University of Virginia; Majid Shafiee-Jood, University of Virginia; Negin Alemazkoor, University of Virginia

Compound flooding in coastal watersheds is fundamentally a dynamic coupling problem: coastal water-level forcing can propagate inland through hydraulically connected pathways, altering stage–discharge relationships, inducing backwater effects, delaying drainage of rainfall-generated runoff, and even reversing flow direction. Conversely, rainfall-driven storage and runoff can modulate the inland penetration and timing of coastal signals. These feedbacks are nonlinear, time dependent, and spatially heterogeneous, and they arise through hydraulic connectivity rather than through any single driver in isolation. While physics-based hydrodynamic models resolve these interactions by synchronizing exchanges between boundary and interior states at each timestep, their computational cost limits large ensembles and real-time forecasting.

Recent deep-learning flood surrogates have improved computational speed, but for compound flooding they often represent coupling implicitly through grid-based feature fusion (e.g., CNN/U-Net and CNN–LSTM surrogates), externally through physics-based boundary exchanges in hybrid workflows, or retrospectively in attribution-focused models. As a result, the boundary–interior interaction that defines compound flooding is not treated as an explicit, learnable, state-dependent mechanism, limiting interpretability and robustness to new combinations of rainfall and coastal forcing.

The central objective of this study is to explicitly learn boundary–interior coupling for compound flood forecasting using a graph-based surrogate that leverages the native hydraulic connectivity of coastal watersheds through connectivity-aware updates. This formulation provides a natural representation of time-varying, bidirectional coastal–inland interactions. Using high-fidelity hydrodynamic simulations as ground truth, we evaluate whether learning coupling improves predictive skill in coupling-sensitive behaviors, including boundary influence propagation, compound peak timing and magnitude under varying rainfall–tide phasing, and inland flood response during backwater-dominated conditions. Comparisons against representative baselines and an interaction-disabled ablation are used to isolate the contribution of learned boundary–interior interaction.

Speaker



Zanko Zandsalimi

Mr | University of Virginia

MS 076: Advances in Modeling Wind and Its Effects on the Built Environment

9:30 AM – 11:30 AM | Location: CHEM 140

Chair(s): Teng Wu; Catherine Gorle; Marco Giometto

Moderators



Marco Giometto

Assistant Professor | Columbia University

ID 155: Machine Learning Enhanced Stationary and Non-Stationary Wind Control in the University of Florida Boundary Layer Wind Tunnel

9:30 AM – 9:50 AM

Author(s): Xiaobang Zhang, University of Florida; Brian Phillips, University of Florida; Jennifer Bridge, University of Florida; Ryan Catarelli, University of Florida; Tai-An Chen, University of Florida

University of Florida's Boundary Layer Wind Tunnel (BLWT) is one of the National Science Foundation's (NSF) Natural Hazards Engineering Research Infrastructure (NHERI) Experimental Facilities (EF). This study presents the application of machine learning (ML) methods in the physical simulation of near-surface stationary and non-stationary extreme wind phenomena in the UF BLWT. A novel artificial neural network (ANN) and a novel recurrent neural network (RNN) were developed to provide seamless control of the three BLWT flow-conditioning stages: vaneaxial fans (VAF), automated roughness elements collectively called the Terraformer (TF), and a multi-fan array called the Flow Field Modulator (FFM), aiming to achieve target stationary and non-stationary flows in the downwind test section. Both neural networks were validated using selected testing sets, and the RNN was further applied to create non-stationary downburst wind fields. The results demonstrate that ML methods can achieve user-specified complex and transient flow conditions. The resultant flow control capabilities expand the limits of flow simulation of large-scale non-stationary winds, enabling realistic modeling of transient wind-induced structural loads and responses.

Speaker



Xiaobang Zhang

PHD Candidate | University of Florida

ID 230: AI-Empowered Physical Modeling of Flow in a Wind Tunnel

9:50 AM – 10:10 AM

Author(s): Baoheng Li, University at Buffalo; Teng Wu, University at Buffalo; Andrew S. Whittaker, University at Buffalo; Scot Weinreber, University at Buffalo

Conventional wind tunnels rely on passive flow-conditioning devices (e.g., roughness elements and spires), which induce turbulence by introducing momentum deficits and strong shear layers caused by flow separation, thereby limiting their ability to generate large-scale turbulence and transient wind fields. In contrast, active devices (e.g., multiple-fan systems and active grids) inject momentum directly through controllable actuation, showing strong potential for generating such complex wind conditions. However, accurately reproducing transient wind fields requires faithful replication of prescribed wind velocity time series, which places stringent demands on both control algorithms and the underlying control system. Existing error-driven model-free control strategies (e.g., offline iterative learning control and proportional–integral–derivative control) are primarily based on tracking errors and are unable to capture the intrinsic spatiotemporal dependency between control inputs and the resulting wind field. The highly complex and nonlinear evolution of turbulence within wind tunnels precludes the development of accurate physics-based models, thereby limiting the applicability of physics-based model-driven control approaches (e.g., model predictive control and state-space optimal control) for transient wind reproduction. In addition, most existing wind tunnels rely on either asynchronous software-timed data acquisition (DAQ) systems, which lack a unified hardware time base for reliable system-wide synchronization, or host-synchronized real-time DAQ systems, where synchronization depends on external timing resources and host scheduling, rendering system timing susceptible to workload- and OS-induced latency, jitter, and non-deterministic performance. Consequently, the controller cannot reliably capture the instantaneous system state, limiting the reproduction of high-frequency wind velocity time series. To address these challenges, we introduce an AI-based control framework that integrates data-driven representation learning (e.g., supervised and unsupervised learning) with learning-based policy optimization (e.g., reinforcement learning), enabling the controller to learn implicit system dynamics directly from measured data and autonomously derive optimal real-time control policies. To enable the deployment of this framework in physical experiments, we further develop an AI-empowered wind tunnel control system with a hardware-synchronized real-time DAQ architecture, ensuring hardware-enforced synchronization, deterministic inter-device communication, and bounded execution latency across the control loop, as well as a high-performance computing server to support training and online updating of control algorithms. This platform is implemented on the University at Buffalo (UB) multiple-fan wind tunnel augmented with vertical and lateral vibration louvers, enabling the generation and real-time control of arbitrary three-dimensional (3D) wind fields.

Speaker



Baoheng Li

PhD student | University at Buffalo

ID 357: Cooling-Source LES of Downburst Generation and Stationary Reconstruction of Extreme Near-Ground Wind Profiles for Building Load Statistics

10:10 AM – 10:30 AM

Author(s): Jianyu Wang, Center for Turbulence Research, Stanford University; Lingqian Zheng, Department of Civil and Environmental Engineering, Stanford University; Catherine Gorlé, Department of Civil and Environmental Engineering, Stanford University

Downbursts produce intense, localized near-ground winds that can govern peak demands on the built environment. A central obstacle for high-fidelity load assessment is that realistic downburst winds are inherently non-stationary: the most extreme velocities at a building location often occur over a brief interval, which makes it difficult to obtain converged second-order turbulence statistics and reliable distributions of surface pressures and integrated forces. This study develops a two-stage large-eddy simulation (LES) framework in CharLES to model downburst physics and to enable statistically stationary sampling of the most critical incident wind profile at the building.

In Stage 1, we implement a cooling-source model that represents the thermodynamic driver of downbursts through a Helmholtz-based formulation coupled with the Boussinesq approximation. The resulting negative buoyancy generates a downdraft that accelerates toward the ground, impinges, and transitions into a radially spreading near-surface outflow. The simulation reproduces key downburst characteristics relevant to wind engineering, including the formation of a near-ground nose-shaped velocity profile, coherent vortex structures, and strong temporal variability in both mean flow and turbulence. However, because the peak winds at the building are transient, the time window for sampling Reynolds stresses and load statistics at the most hazardous condition is limited.

Stage 2 aims to reproduce the extreme near-ground wind profile in a stationary manner so that turbulence metrics and wind loads can be sampled over long durations. Two complementary approaches are pursued. The first is a geometry-based method that explicitly resolves upstream flow-conditioning structures, such as louvers or guide vanes, to shape the incoming flow and promote a nose-shaped profile at the building. Its primary challenge is the difficulty of establishing a precise, controllable mapping from conditioner geometry to the resulting mean profile, while also independently regulating turbulence intensity and structure. The second is a purely numerical approach that prescribes the target flow at the building location using volume forcing for anisotropic turbulence together with a mean-profile sponge that stabilizes the desired mean shear. The prescribed targets are derived from the Stage 1 extreme-profile snapshot and are enforced to achieve stationarity without relying on physical guide structures.

The two approaches will be evaluated and compared based on profile fidelity, stationarity, Reynolds-stress and spectral agreement, and resulting surface pressure and force statistics on canonical building configurations, with the goal of providing a practical pathway for LES-based downburst wind-load characterization.

Speaker



Jianyu Wang

Dr. | Stanford University

ID 403: Agentic AI-based Autonomous Meshing for CFD

10:30 AM – 10:50 AM

Author(s): Fei Ding, University of Utah; Teng Wu, University at Buffalo

Computational Fluid Dynamics (CFD) plays a critical role in modeling wind effects on structures and built environment. Nonetheless, setting up a single CFD simulation typically requires deep domain expertise, specialized technical skills, and substantial manual effort. Although open-source software such as OpenFOAM is a mature and widely used platform, its reliance on expert knowledge for preparing configuration files and debugging through command-line interfaces limits broader adoption for non-CFD experts and often compromises simulation reliability.

Recent advances in Large Language Model (LLM)-based agents offer a promising solution to automate CFD workflows through natural languages. The LLM-driven CFD automation primarily leverages Retrieval-Augmented Generation (RAG) to integrate CFD domain knowledge with general-purpose language models. RAG enables access to databases of existing OpenFOAM tutorials, providing relevant examples that guide case setup and improve modeling precision. Existing pioneering frameworks, such as MetaOpenFOAM, ChatCFD, and OpenFOAMGPT, demonstrated the ability to interpret natural-language instructions, coordinate multi-step tasks, and automatically generate OpenFOAM configuration files.

While existing agent-based approaches provide strong capabilities in automating the overall configuration of CFD cases, a critical gap remains in the automated generation of computational meshes across varying model fidelities, particularly in physically sensitive regions such as near-wall boundary layers. This limitation is especially pronounced in simulations of wind flow around civil structures. Mesh generation is not merely a geometric task but a physics-driven process that requires an understanding of flow physics, turbulence modeling, and boundary layer theory. As a result, mesh quality needs to be coupled with turbulence model fidelity and adaptively refined in physically sensitive regions, such as near-wall boundary layers where steep gradients occur. Inappropriate mesh resolution in these regions can lead to physically incorrect predictions of flow separation and aerodynamic loads on structures.

To address this gap in current automated CFD workflows, we propose a novel agent-based framework featuring a hierarchical RAG pipeline tailored for advanced meshing tasks. The core architecture of the mesh agent integrates two retrieval components: a reference retriever, which accesses a specialized knowledge base of CFD best practice guidelines, OpenFOAM tutorials, and CFD models extracted from relevant journal articles on wind flow simulations to provide detailed meshing strategies; and a context retriever, which extracts case-dependent constraints, such as geometry, turbulence model and inflow conditions, from multi-modal user inputs to guide physics-aware mesh refinement. Therefore, the framework is capable of explicitly incorporating physical knowledge and CFD best practices to adaptively refine meshes, moving beyond basic tutorial templates to create more reliable and physically consistent mesh refinements.

To validate the capabilities of the proposed framework, we will conduct a demonstrative case study simulating wind flows around tall buildings with varying geometries and using different levels of CFD model fidelity. The overarching goal of this study is to democratize access to CFD by enabling advanced simulation capabilities for a broader range of engineering problems that were previously intractable for non-experts.

Speaker



Fei Ding

Assistant Professor | University of Utah

ID 429: Windborne Debris Risk Analysis Using Synchronized Building Surface Pressure and Surrounding Flow Field

10:50 AM – 11:10 AM

Author(s): Kimia Yousefi Anarak, Colorado State University; Shaopeng Li, University of Louisiana at Lafayette; Ryan Catarelli, University of Florida; Yanlin Guo, Colorado State University; Kurtis Gurley, University of Florida; John van de Lindt, Colorado State University

Windborne debris may impact and cause damage to building exteriors during extreme winds. The debris may be generated from loose material or from failures of building exterior components induced by previous windborne debris impacts or excessive wind pressure. For debris generated from loose material or by previous windborne debris impacts, initiation and subsequent flight can be numerically modeled based solely on wind flow characteristics. In contrast, debris resulting from failed components due to excessive wind loads on the building envelope requires synchronized evaluation of wind induced pressure coefficients and flow field to determine both the initiation timing and subsequent trajectories, which is not fully addressed in existing studies. In this study, a computational fluid dynamics (CFD) simulation is used to investigate debris initiation from building exterior surfaces and its subsequent propagation within the flow field. The numerical setup follows the configuration of the recent wind tunnel experiments that studied debris flight in highly turbulent boundary layer flows. The simulation reproduces a mean wind speed of 7.3 m/s, and a turbulence intensity of 23.7% at building height, and a 45° orientation relative to the incoming flow. The building has a square plan of 0.5 m×0.5 m and a height of 1 m. Three scenarios with increasing complexity are considered: (1) debris released from the exterior surface and propagated in the time-averaged mean flow, (2) debris released from the exterior surface and propagated in the time-varying instantaneous flow, and (3) debris released at the time of the peak exterior wind pressure and propagated in the instantaneous flow, representing the debris generation mechanism due to exterior component failure. For the first two cases, debris is released from a rooftop location along the centerline of the most severe scouring region observed in the wind tunnel experiments, beneath the conical vortex. The wind field obtained from the CFD simulation is then integrated into a debris flight numerical model based on Newton's second law to compute debris trajectories. For the third case, the time history of pressure obtained from the CFD simulation is used to determine the timing and location of debris initiation, while the CFD-predicted wind field is used in the debris flight model to compute debris trajectories. The resulting flight trajectory statistics for the three cases are compared to assess the role of peak pressure in debris generation, and the influence of flow fluctuations on debris generation and transport, contributing to an improved understanding of progressive damage mechanisms affecting building exteriors during extreme winds.

Speaker



Kimia Yousefi Anarak
Colorado State University

ID 570: Self-Driven and Data-Efficient Wind Flow Prediction via Adaptive Experimental Sampling

11:10 AM – 11:30 AM

Author(s): Arezoo Bakhshizadeh, Florida State University; Pedro Fernandez-Caban, Florida State University

Wind tunnel modeling remains the primary research tool for accurately characterizing wind flows and their interactions with the built environment. However, traditional wind tunnel testing approaches are often time-consuming and costly, and can lack adaptability in measurement planning. Conversely, experimental automation and AI-integrated strategies can significantly enhance decision-making in experimental design, while improving precision, repeatability, and data efficiency. This study explores a self-driven experimental framework that integrates adaptive sampling and surrogate modeling to predict complex wind flow behavior around isolated and non-isolated building structures. Experiments were conducted in the FAMU–FSU College of Engineering open-circuit low-speed (suck-down) wind tunnel. The setup includes automated sensor positioning and upstream obstacles with varying dimensions and arrangements to investigate channeling and sheltering effects. These morphometric configurations emulate realistic urban conditions and enable systematic analysis of complex flow behaviors (e.g., separation, wake development, and large velocity and pressure gradients). Adaptive sampling is integrated to identify and probe regions of high flow complexities, which are prioritized by the algorithm to maximize information gain while minimizing redundant measurements. A surrogate model predicts spatial regions based on prior observations and updates its predictions as new data is collected, gradually improving until convergence. The proposed self-driven wind tunnel approach aims to enhance our understanding of wind–structure interactions in real-world urban landscapes.

Speaker



Arezoo Bakhshizadeh
Graduate Assistant | Florida State University

MS 088: Advances in Damage Mechanics and Micromechanics - in Honor of the 2025 Blaise Pascal Medal in Engineering to Professor Jiann-Wen Woody Ju

9:30 AM – 11:30 AM | Location: UMC 247

Chair(s): Huiming Yin; Lizhi Sun; Glaucio Paulino; Yong-Rak Kim

Moderators



Huiming Yin
Associate Professor | Columbia University

ID 151: A Novel Explicit Micromechanical Model for Homogenized Effective Elastic Moduli of Random Composite Materials

9:30 AM – 9:50 AM

Author(s): Liam P. Deng, University of California, Los Angeles; J. Woody Ju, University of California, Los Angeles

Random heterogeneous composite materials are widely used in civil engineering, mechanical engineering, aerospace materials, and bioengineering, etc., and precise prediction of their effective elastic stiffness is of great importance and remains a fundamental problem in micromechanics of material. A novel explicit micromechanical model is proposed to estimate the homogenized effective elastic moduli (stiffness) of random composite materials. The present model renders accurate predictions for a wide range of volume fractions, especially in the dense regime where most classical models underestimate the effective elastic moduli because they do not appropriately include particle interactions. To account for particle interaction effects, each phase (inhomogeneity) is assumed to be embedded in a newly introduced effective surrounding medium. The stiffness of this fictitious medium is defined as a volume-fraction-weighted general mean of all the phase stiffnesses with one single material-independent mechanical parameter p . The value $p = -1$ was chosen from matching to a reliable test from the literatures. Closed-form expressions are presented for effective bulk and shear moduli in two-phase random systems, and the variant formulas are derived for porous materials. To verify the performance and stability of the present model, several numerical simulations are carried out and compared with select experimental results in the literature. The numerical predictions lie within the Voigt-Reuss bounds and the Hashin-Shtrikman bounds. Despite a minor exceedance of the three-point upper bound for the bulk modulus, the present predictions agree closely with several widely cited experimental datasets. The new model avoids the singular growth observed in the curves from the celebrated pairwise particle interaction model. Overall, the proposed model provides a simple and accurate set of explicit solutions to estimate the effective elastic material properties, and it exhibits improved numerical predictions than classical models, e.g., the Eshelby's model, Mori-Tanaka model, and generalized self-consistent model, etc. The present framework is computationally efficient, fully explicit, and readily applicable to scientific study and engineering design of random composite materials.

Speaker



Liam Deng

Mr. | University of California, Los Angeles

ID 187: Effective hysteresis of magnetorheological composites due to interfacial debonding

9:50 AM – 10:10 AM

Author(s): Shengwei Feng, UC Irvine; Lizhi Sun, UC Irvine

It is recognized that microstructures of magnetorheological elastomers (MREs) significantly influence their effective hysteresis behavior under the applied magnetic field. While the interaction between embedded particles and the polymeric matrix is commonly suggested as a causal factor, the underlying microstructural mechanisms remain unclear. This study employs a micromechanical-based model to examine the impact of interfacial debonding and friction of embedded particles on MREs under the cyclic loading conditions. Findings reveal that interface conditions critically affect the mechanical behavior of MREs, particularly in terms of damping. It is evident that particles, varying in interface condition and relative position within the matrix, contribute distinctly to the overall dynamic properties under different magnetic field intensities.

Speaker



Lizhi Sun

Professor | UC Irvine

ID 232: A Smeared Joint Model for Extrusion-Based 3D Printed Concrete

10:10 AM – 10:30 AM

Author(s): Chunpeng Qu, FAMU-FSU College of Engineering; Qian Zhang, FAMU-FSU College of Engineering

Extrusion-based 3D-printed concrete (3DPC) is fabricated through a layer-by-layer deposition process in which each new filament is placed onto previously printed material. Unlike cast concrete, the interlayer regions created during printing are often characterized by imperfect bonding, entrapped air, moisture gradients, and time-dependent surface evolution, which collectively lead to comparatively weak joints. These weak joints introduce pronounced directionality in mechanical behavior, resulting in mechanical anisotropy and orientation-dependent failure modes. Consequently, conventional constitutive models developed for isotropic cast concrete are generally unable to reproduce these key characteristics of 3DPC response. Accurate analysis and design of 3DPC structures therefore require new constitutive formulations that explicitly account for joint-induced anisotropy and the associated failure mechanisms.

This study presents a continuum-based multi-surface plasticity model for 3DPC. Building on the smeared joint concept, 3DPC is treated as an elastoplastic continuum in which inelastic deformation is decomposed into three mechanisms: (i) bulk concrete matrix deformation, (ii) joint sliding, and (iii) joint opening. Different yield criteria are employed for each mechanism: the bulk matrix response is described using a concrete damage plasticity formulation, while the joint response is modeled using a Mohr–Coulomb criterion for joint sliding with a tensile cut-off for joint opening. To enable robust numerical implementation of the coupled multi-surface formulation, an implicit return-mapping algorithm with an active-set strategy is introduced, and the consistent algorithmic tangent operator is derived for finite element implementation.

Stress-point simulations demonstrate that the proposed model captures strength variations with joint orientation and reproduces the transition in the governing failure mode from matrix-dominated failure to joint-dominated failure as the joint orientation changes. Parametric studies further show that joint strength significantly influences the overall strength when joint failure is dominant. Overall, the results indicate that the proposed constitutive model provides a practical means for simulating anisotropic strength and failure in 3DPC, with potential for efficient large-scale finite element analyses of 3DPC structures.

Speaker



Chunpeng Qu

Florida State University

ID 249: Direct correlation function-dependent homogenization

10:30 AM – 10:50 AM

Author(s): Anna Gorgogianni, Cornell University; Chloé Arson, Cornell University

Correlation functions, the microstructure descriptors capturing the spatial arrangement of the constituent phases in a composite material, are well-known for their profound effect on the effective material behavior. Accurate approximations to the effective material properties of statistically homogeneous composites with distinct homogeneous phases of random spatial arrangement (non functionally-graded materials), can be found in well-established, correlation function-dependent bounds, such as those derived by Milton and Torquato. Nevertheless, these bounds are challenging to compute, involving integrals of up to four-point correlations. In addition, correlation functions are analytically tractable only for idealized microstructure geometries, such as composites with spherical inhomogeneities.

To circumvent these challenges, this study proposes a semi-analytical correlation function-dependent homogenization scheme that provides direct estimates to the effective stiffness tensor. The salient feature of the model is that it introduces accurate analytical approximations to the phase strain localization tensors, i.e. the fourth-order tensors that relate the average strain inside a given phase with the average strain in the composite, in terms of appropriate two-point correlation functions. These low-order correlation functions can be computed numerically on microstructures with phases of arbitrary shape. The effective stiffness tensor of the composite is then calculated from the direct approach, which relates it to the phase properties and the phase strain localization tensors.

The model is applied on linearly elastic two-phase composites consisting of a matrix with randomly dispersed, non-penetrable as well as fully penetrable, spherical inhomogeneities. The predicted effective stiffness tensor is in close agreement with the corresponding approximations by Milton and Torquato. The model's predictions are also validated against full-field simulations with the finite element method (FEM). It is shown that the scheme can provide a good estimate of the FEM-computed effective stiffness. Because the model is formulated in terms of correlation function-dependent phase localization tensors, it provides a coarse resolution of the numerically resolved microscale strain field in the composite.

We have thus introduced a scheme that is as accurate as the well-established correlation function-dependent bounds, yet more convenient from an implementation viewpoint, as well as generalizable to more complex microstructure geometries. Future extensions of this research will investigate composites with angular inhomogeneities, as well as multi-phase composites.

Speaker



Anna Gorgogianni

Postdoctoral Associate | Cornell University

ID 446: Multiphysics Multiscale Mechanical Modeling of Permafrost Subgrade on the Qinghai–Tibet Plateau for Digital Twin Applications

10:50 AM – 11:10 AM

Author(s): Yingjie Deng, State Key Laboratory of Green and Long-Life Road Engineering in Extreme Environment, CCCC First Highway Consultants Co., LTD; Shuangjie Wang, State Key Laboratory of Green and Long-Life Road Engineering in Extreme Environment, CCCC First Highway Consultants Co., LTD; Jiann-Wen Woody Ju, University of California, Los Angeles; Jianbing Chen, State Key Laboratory of Green and Long-Life Road Engineering in Extreme Environment, CCCC First Highway Consultants Co., LTD; Shengliang Cao, State Key Laboratory of Green and Long-Life Road Engineering in Extreme Environment, CCCC First Highway Consultants Co., LTD

Traditional macroscopic mechanical models for permafrost subgrades are inadequate to meet the requirements of synchronous operation and high-precision prediction in Digital Twins, creating an urgent need for multi-physics multi-scale mechanical models that can capture full life-cycle structural evolution. Focusing on permafrost subgrades on the Qinghai-Tibet Plateau, this paper proposes a multi-physics multi-scale mechanical modeling framework. At the microscale, a permafrost microstructural model is developed that considers the effects of particle state, particle rotation and sliding, pore microstructure, and ice-crystal morphology. Temperature and ice saturation are introduced as cross-scale state variables, and a damage variable D is defined to characterize degradation and load-bearing capacity decay under the freeze–thaw actions. A micromechanical constitutive model is derived and solved using a bonded-particle discrete element method. Computational homogenization based on representative volume elements is then performed to obtain the equivalent tangent stiffness tensor C , equivalent strength parameters c and ϕ , and the damage evolution law. Then, a macroscopic state-equation framework for permafrost subgrades under coupled thermo–hydro–mechanical processes is developed. The proposed multi-physics multi-scale mechanical model is validated against the in-situ temperature records, settlement data, as well as InSAR observations. The results demonstrate that the framework can satisfactorily reflect the spatio-temporal evolution of subgrade deformation under transient thermal disturbances.

ID 795: A Framework for Image-Based Coupled 3D Electrochemical–Mechanical Damage Simulation in Fuel Cell and Electrolyzer Electrodes Using Reproduced Kernel Particle Method (RKPM)

11:10 AM – 11:30 AM

Author(s): Xin He, the Naitonal Laboratory of the Rockies; Jeff Allen, the Naitonal Laboratory of the Rockies; Kristen Susuki, the Naitonal Laboratory of the Rockies; Jacob Wrubel, the Naitonal Laboratory of the Rockies

This work presents a coupled electrochemical–mechanical simulation framework for fuel cells and electrolyzers based on the Reproducing Kernel Particle Method (RKPM). A simplified electrochemical formulation is adopted in which Poisson equations govern the electric potential distribution in the electrolyte and the concentration fields in the porous electrode. The resulting concentration evolution within the electrode is subsequently used to drive a mechanical analysis that predicts stress development and damage initiation under operating conditions. After introducing the governing equations and numerical formulation, the proposed RKPM approach is verified through comparison with finite element method (FEM) solutions for representative electrochemical–mechanical loading scenarios based on a simple geometry. A comprehensive parametric study is then conducted to assess the influence of key material and operating parameters on the predicted mechanical response and damage evolution. The results demonstrate the capability of the RKPM framework to capture the coupled multiphysics behavior of electrochemical devices and provide insight into the reliability and design optimization of fuel cell and electrolyzer components.

Speaker



Xin He

Computational Scientist | the Naitonal Laboratory of the Rockies

Moderatorss



Jianqiang Wei

Assistant Professor | University of Maryland



Yen-Fang Su

Assistant Professor | Louisiana State University

ID 161: Experimental and Numerical Assessment of the Axial Strength of Ultra-High Performance Concrete Hollow Columns

9:30 AM – 9:50 AM

Author(s): Yuqing Tan, Southeast University & University of California Davis; Michele Barbato, University of California Davis; Zhao Cheng, Southeast University

Hollow concrete columns are frequently used in high-rise buildings and long-span bridges, owing to their advantageous cross-sectional properties and reduced weight. The integration of ultra-high performance concrete (UHPC) with a hollow cross-section has been demonstrated to enhance the mechanical properties of the resultant columns. However, the confinement effect of transversal steel reinforcement in UHPC hollow columns remains only partially understood. In order to enhance engineering knowledge of this confinement effect, an experimental campaign was performed to investigate the impact of hollow ratio, steel fiber relative volume content, and transversal steel reinforcement ratio on the peak strength of UHPC hollow columns transversally reinforced with single-layer steel spirals. Each experimental test considered three nominally identical specimens to assess the aleatoric uncertainty in the peak strength. A moderate general trend of peak strength increase was observed for decreasing hollow ratio, increasing steel fiber relative volume content, and increasing transversal steel reinforcement ratio, although the aleatoric variability of the experimental results and the limited number of specimens do not allow for strong conclusions. A 3-dimensional nonlinear finite element model of the different experimental specimens was developed using a Concrete Damage Plasticity (CDP) model for UHPC. The dilation angle and the ratio of biaxial to uniaxial compressive yield stresses, for which no consensus was found in the literature, were calibrated by using unreinforced UHPC hollow and solid columns. The calibrated parameters were found to provide good agreement between the experimentally measured and the numerically estimated values of the peak strengths for the UHPC columns considered in this study, with differences ranging between -12% and +16% and an average error smaller than 1%.

Speaker



Tan Yuqing

University of California, Davis

ID 284: Experimental and Computational Investigation of Rheological Behavior of Cellulose Nanofibers-Enhanced Ultra-High-Performance Concrete

9:50 AM – 10:10 AM

Author(s): Xiaoli Xiong, Purdue University; Rongze Hu, Purdue University; Yongfei Li, Purdue University; Kamal Khayat, Missouri University of Science and Technology; Chengcheng Tao, Purdue University

Cellulose nanofiber (CNF) is a renewable bio-based nanomaterial, derived from wood pulp, with promising applications in cementitious materials. Conventional nanomaterials, including nano-silica, employed in ultra-high-performance concrete (UHPC) are frequently associated with high embodied carbon dioxide emissions and potential respiratory health hazards. In this study, ultrasonicated CNF aqueous suspensions were prepared and incorporated into UHPC at dosages of up to 1.5 kg of CNF per m³ of UHPC. The rheological behavior of CNF-enhanced UHPC was investigated through both experimental measurements and numerical simulations. Rotational shear rate-controlled ramp up and ramp down experiments were conducted using an Anton Paar MCR 302E rheometer equipped with a "cup-and-vane" Building Material Cell. The results show that the CNF suspension exhibits pronounced shear-thinning behavior, which becomes increasingly significant with higher CNF concentrations. By fitting the shear stress-shear rate profile to the Herschel-Bulkley model, it was found that the incorporation of CNF substantially alters the rheological behavior of UHPC, resulting in a significant increase in yield stress and enhanced shear-thinning behavior with increasing CNF dosage. In addition, CNF strongly affects the time-dependent rheological behavior of UHPC, with thixotropy becoming more pronounced as the CNF content increases. The combination of high yield stress, shear-thinning behavior, and pronounced thixotropy makes CNF-enhanced UHPC particularly suitable for 3D printing applications, as it can be readily extruded through a nozzle under high shear while resisting collapse after being printed out. With information from rheological experiments, a numerical 3D printing simulation using Ansys Fluent 2024 R1 was then performed to evaluate the flow behavior of CNF-enhanced UHPC through a cone-shaped 3D printing nozzle. The CNF-enhanced UHPCs achieved a stable and consistent flow within 0.002 s of extrusion when the inlet mass flow rate was 0.06 kg/s. Although the incorporation of CNF increases the yield stress and inlet pressure of UHPC, it can still rapidly establish a stable and continuous flow inside the nozzle, with smooth velocity gradient and effective extrusion performance. The simulation results confirm that CNF-enhanced UHPC has excellent printability, making it a promising candidate for 3D printing applications.

Speaker



Xiaoli Xiong

PHD student | Purdue University

ID 685: Self-Sensing CNT/Epoxy Concrete for Rapid Pothole Repair and Post Repair Monitoring

10:10 AM – 10:30 AM

Author(s): Yu-Jin Jung, Hanyang University ERICA; Ga-Hyeon Eom, Hanyang University ERICA; Sung-Hwan Jang, Hanyang University ERICA

This study proposes a self-sensing CNT/epoxy concrete designed for rapid pothole repair and post repair monitoring. The material consists of carbon nanotube reinforced epoxy combined with aggregates, forming an epoxy concrete suitable for pavement repair applications. During Joule heating, electrical resistance variation and a rapid temperature rise are simultaneously observed, which significantly accelerates the curing process. As a result, the conventional curing time of approximately 48 hours is reduced to 1 to 2 hours, enabling fast reopening of traffic after repair. To ensure stable and efficient heating performance, the optimal applied voltage was systematically investigated according to CNT concentration and aggregate content. After curing, the CNT/epoxy concrete exhibits distinct electromechanical responses under service conditions. Electrical resistance increases progressively with surface wear, allowing assessment of usage level and degradation of the repaired pothole area. In addition, a decrease in electrical resistance is observed under compressive loading, indicating reliable load sensitive behavior for traffic induced stress monitoring. These results demonstrate that the proposed CNT/epoxy concrete functions not only as a rapid repair material but also as an integrated sensing medium, highlighting its potential for smart pavement maintenance systems.

Speaker



Yu-Jin Jung

Ph.D. candidate | Hanyang University ERICA

ID 697: Bio-based alkali-activated starch hydrogel coatings for evaporation control and early-age shrinkage mitigation in UHPC and cementitious mortar

10:30 AM – 10:50 AM

Author(s): Aniket Kumar Patel, Arizona State University; Maedeh Hesami, Arizona State University; Asif Jalal, North Dakota State University; Avinaya Tripathi, Arizona State University; Narayanan Neithalath, Arizona State University; Ravi Kiran, Arizona State University

Early-age moisture loss from exposed cementitious surfaces lowers internal relative humidity and accelerates shrinkage development, thereby increasing the likelihood of cracking and durability-related deterioration, particularly in mixtures with low water-to-binder ratios. This study examines alkali-activated corn-starch hydrogels as bio-based, membrane-forming surface curing coatings intended to suppress evaporation and improve early-age deformation. Three formulations were produced by varying starch content (2-4 wt.%) while maintaining constant NaOH and glycerol dosages and were characterized using Fourier-transform infrared spectroscopy (FTIR), oscillatory rheology, and optical microscopy. Coating performance was assessed on ultra-high-performance concrete (UHPC) and a cementitious (OPC and limestone: 70% and 30% by mass, denoted as L30) mortar using drying shrinkage measurements, time-dependent mass-loss tracking, and high surface-exposure drying tests over the first 48 h. The measured mass-loss response was decomposed into contributions from hydrogel desiccation and substrate drying by testing identical hydrogel layers on an inert, non-absorptive base and using the corresponding response as a formulation-specific correction. Across both substrates, hydrogel application reduced early-age substrate moisture loss and lowered drying shrinkage relative to untreated controls, with the largest benefit observed for UHPC. Among the tested formulations, the 2 wt.% hydrogel (H2) provided the most consistent balance between application behavior and curing efficiency, reducing drying shrinkage by approximately 32% and cumulative mass loss by approximately 20% in UHPC at the evaluated age. Microscopy indicated that higher hydrogel concentration increased liquid-phase ingress into the near-surface pore network and altered the distribution of coating material between penetration depth and external film thickness, particularly for the more permeable L30 substrate, which corresponded to reduced effectiveness at the highest concentration. Overall, the results demonstrate that alkali-activated starch hydrogels can serve as sustainable curing layers that limit early-age evaporation demand and enhance dimensional stability in high-performance cementitious materials.

Speaker



Aniket Patel

Graduate Research Scholar | Arizona State University

ID 757: Combined Effect of Cyclic Loading and Autogenous Healing on the Flexural Performance of PVA-FRCC

10:50 AM – 11:10 AM

Author(s): Reina Nette Daguio, The Hong Kong University of Science and Technology; Jishen Qiu, The Hong Kong University of Science and Technology

The mechanical performance of Polyvinyl Alcohol Fiber Reinforced Cementitious Composites (PVA-FRCC) significantly depends on the capacity of the material to sustain damage and its subsequent ability to recover fiber-bridging capacity. An important aspect that can affect the long-term properties of these composites is the interplay between mechanical fatigue history and autogenous healing, which is a process wherein the cementitious matrix undergoes repair after being damaged. In this study, we investigate the combined influence of fatigue preloading and environmental conditioning on the flexural performance of PVA-FRCC using a notched three-point bending configuration.

In the experimental setup, PVA-FRCC beam specimens were subjected to three distinct cyclic preloading regimes of 1,000, 10,000, and 30,000 cycles at a peak load of 400 N to induce varying degrees of microstructural damage. This was followed by a controlled environmental conditioning phase designed to promote the formation of healing products. The effectiveness of the combined cyclic preloading and healing process was assessed by performing notched three-point bending tests on the treated specimens. For comparison, specimens that were mechanically preloaded to identical fatigue levels but not subjected to the healing process were also evaluated to isolate the specific effects of mechanical loading, alongside a pristine group used for baseline normalization.

The peak load, Crack Mouth Opening Displacement (CMOD) at peak, and total energy absorption of the specimens were quantitatively assessed. Additionally, a normalized History Index (HI) was calculated to quantify performance relative to the pristine baseline. The analysis revealed that mechanical cycling alone provides a significant strain hardening benefit. For instance, the 10,000-cycle history group exhibited a 10% increase in peak load compared to the pristine baseline, which may be attributed to the fatigue-induced increase in frictional bond at the fiber-matrix interface. Furthermore, the study identified a synergistic relationship wherein the 10,000-cycle healed specimens demonstrated a 20% increase in peak load compared to the pristine baseline. This suggests that the microcracks generated by fatigue provide pathways for healing agents to penetrate and form healing products at the fiber-matrix interface. While energy absorption showed no significant deviation after cyclic preloading alone, it notably increased following the healing phase. Ultimately, this research clarifies that the post-healing performance of PVA-FRCC is a cumulative result of both mechanical and environmental conditioning.

Speaker



Reina Nette Ruiz Daguio

PhD Candidate | The Hong Kong University of Science and Technology

ID 518: Physics-Informed Machine Learning for Ultrasonic Non-destructive Evaluation of Concrete affected by Alkali-Silica Reaction

11:10 AM – 11:30 AM

Author(s): Mohammed Alnaggar, Oak Ridge National Laboratory; Hongbin Sun, Oak Ridge National Laboratory

Alkali-Silica Reaction (ASR) is considered the concrete cancer. Its initiation and early spread is often not noticed until significant distributed cracking becomes visually detectable. Therefore, it is crucial to be able to effectively detect it and to quantify its extent. Non-destructive evaluation (NDE) using ultrasonic wave propagation techniques is one of the most researched methods for detecting ASR given its sensitivity to cracking. However, multiple challenges emerge from the correlation of the observed cracking signatures in the collected wave with the degree of damage and cracking. This applies to both linear and nonlinear acoustic measures. Many of those signatures are relative changes (e.g. acoustic nonlinearity parameter) rather than absolute values (e.g. sound speed or attenuation). In addition to this challenge, concrete is very versatile and has a wide range of properties. Thus, different concretes would have different ASR expansion extents and different time evolutions of such expansion that also depend on the environmental conditions. The work presented here shows how to integrate chemical and physical information about the affected concrete with advanced 1D and 2D convolutional Neural Networks (CNNs) to better inform the prediction of the extent of ASR expansion directly from analyzing the received ultrasonic wave. Time-domain signals are input to the 1D CNNs and both time-domain and frequency domain signals are input to the 2D CNN. Physics is introduced through different methods. One direct way is by the addition of data like concrete age, mix design, and/or environmental conditions directly as inputs together with the received signal. Another approach is to use such data to compute ASR expansion envelopes from physics-based and/or other ML models and then use these envelopes as additional constraints on the CNN loss function during training. The presentation will show the different levels of physics-informing into the CNN and the improved prediction accuracy. A comparison will be also provided with baseline shallow neural networks and deep neural networks without any physics-informed inputs.

Speaker



Mohammed Alnaggar

Senior Research Scientist | Oak Ridge National Laboratory

MS 067: Computational statistics for natural hazards engineering: Advances in Uncertainty Quantification, Surrogate Modeling, and Dimension Reduction for Performance-based design of Structures and Systems

9:30 AM – 11:30 AM | Location: UMC 382-384-386

Chair(s): Dimitris Giovanis; Somdatta Goswami; Bowei Li; Michael Shields; Seymour Spence; Alexandros Taflanidis

Moderators



Bowei Li

Faculty | Texas Tech University

ID 102: Explainable Trajectory Modeling for Convective Storms with Data-Driven Tracks

9:30 AM – 9:50 AM

Author(s): Guangzhao Chen, Texas tech University; Shengshen Li, Texas Tech University

Accurate short-term prediction (0–30 min) of convective storm trajectories is a critical component of impact-based early warning systems and fundamental to the advancement of Performance-Based Wind Engineering. While traditional radar extrapolation methods perform adequately for linear systems, they rapidly degrade when storms undergo complex turning or acceleration, the aerodynamics often associated with high-impact non-synoptic wind events. To address this limitation, this study presents an end-to-end, physically structured, and explainable trajectory modelling framework. We fuse radar-derived storm-core tracks with high-fidelity surface data from the West Texas Mesonet. NEXRAD Level II volumes are processed utilizing the LROSE/TITAN architecture to generate quality-controlled 3D cell trajectories and velocities. These are coupled with Mesonet variables (wind, pressure, temperature, and humidity), which are transformed into a storm-relative coordinate frame. To capture critical front–rear and cross-track asymmetries, environmental data is summarized by motion-aligned quadrants and augmented with terrain descriptors derived from SRTM. The predictive core utilizes a Sequence-to-Sequence (Seq2Seq) Long Short-Term Memory (LSTM) network to forecast future storm velocities. These predictions are kinematically integrated to determine position, a constraint that ensures smooth motion and mitigates physically implausible trajectory jumps. Furthermore, to overcome the “black box” limitations of deep learning, we employ post-hoc DeepSHAP analysis. These attributes predicted the wind velocity components based on wind field asymmetry, pressure forcing, thermodynamics, and terrain interactions. This framework enables regime-dependent interpretation and failure diagnosis, demonstrating superior performance against persistence, extrapolation, and kinematics-only baselines, ultimately providing a more robust tool for characterizing wind hazards in engineering applications.

Speaker



Shengshen Li

PhD Student | Texas Tech University

ID 321: Data-Driven Seismic Risk Assessment Aided by Supervised Neural-based Excitation Embeddings Learned from Ground-Motion Records

9:50 AM – 10:10 AM

Author(s): Parisa Toofani Movaghar, University of Notre Dame; Alexandros Taflanidis, University of Notre Dame

Seismic risk assessment, at either the individual building level or the regional scale, plays an important role in supporting well-informed decisions for seismic performance enhancement and disaster mitigation. Comprehensive seismic risk assessment commonly relies on nonlinear response history analysis (NLRHA), enabling high-fidelity quantification of damage, loss, and recovery. However, the computational cost of NLRHA-based workflows increases with numerical model resolution and with the number of analyses needed. In practice, to support performance-based decision making, extensive ensembles of simulations across a wide range of ground motions, intensity levels, and structural configurations are required to propagate seismic-hazard and infrastructure-model uncertainties to capture the variability in engineering demand parameters (EDPs). This reliance on large NLRHA ensembles constitutes a major computational bottleneck for performance-based risk assessment. Surrogate models offer a practical path to accelerate these workflows by learning a mapping from structural parameters and seismic excitations (inputs) to structural response quantities of interest (outputs), using a small number of judiciously chosen simulations, typically referred to as training points. However, their key barrier for seismic applications is the high dimensionality of earthquake acceleration time histories, which can substantially increase the number of NLRHAs required to achieve reliable surrogate accuracy. Dimensionality reduction (DR) can mitigate this challenge by compressing the excitation, yet conventional DR approaches often prioritize reconstructing the input (ground motion time series) rather than preserving the excitation characteristics that matter most for predicting structural responses. This study proposes a data-driven framework for structural response prediction that couples surrogate modeling with a dimensionality-reduction module for ground-motion excitations. Specifically, earthquake acceleration time histories are compressed into nonlinear latent excitation embeddings using an autoencoder, and the encoder is trained jointly with the surrogate model in an end-to-end setting. Unlike conventional dimensionality reduction that is optimized primarily for reconstructing the input signal, the proposed coupled training is guided by response-prediction accuracy, ensuring that the learned embeddings retain the excitation characteristics most relevant to EDP estimation. Three different formulations are established and compared, unsupervised (i.e., reconstruction only), supervised (predictive accuracy only), and a hybrid approach that considers both reconstruction and predictive model accuracy. The inclusion of additional explanatory variables as inputs for the surrogate model is also considered. The framework is illustrated for regional vulnerability assessment, utilizing a multi-tier validation across diverse ground motions of varying intensities and frequency content, and multiple archetype structural configurations. Results confirm that the proposed framework substantially reduces computational demands while achieving reliable accuracy.

Speaker



Alexandros Taflanidis

Professor | University of Notre Dame

ID 496: Bayesian Inference of Independent and Progressive Failure Mechanisms in Wind-Induced Structural Damage

10:10 AM – 10:30 AM

Author(s): Jordan Nakayama, Auburn University; David Roueche, Auburn University

Understanding how aerodynamic, environmental, and structural characteristics influence behavior is essential for improving resilience to extreme wind events. This study develops and contrasts two Bayesian modeling frameworks to evaluate wind-driven structural damage using a unified, post-event building performance dataset that includes cross-regional U.S. windstorms.

The initial modeling approach employs a series of independent Bayesian binary logistic regressions, where each damage state - none, envelope, substrate, and structural - is treated as a separate outcome. This independent failure mechanism framework enables the isolation of key predictors associated with specific damage types without assuming a sequential relationship among failure modes. The model is motivated by the physical premise that structural systems often fail at their weakest point, with failure occurring at any stage depending on local vulnerabilities rather than a uniform sequence. Predictors include wind speed, terrain, roof geometry and material, age, and construction attributes derived from regional building codes.

While the independent failure model identifies critical factors influencing individual failure types, structural systems are also governed by load paths that suggest an idealized top-down progression of damage, from the exterior envelope to the internal structure. To capture this potential cascading behavior, a second modeling framework, based on a Bayesian continuation-ratio model, was developed. This progressive failure approach models the conditional probability of advancing to more severe damage states given the attainment of preceding ones. Separate binary regressions are used for each transition (e.g., none to envelope, envelope to substrate, substrate to structural), thereby enabling stage-specific inference and enforcing monotonic progression consistent with physical expectations.

Both modeling frameworks leverage the strengths of Bayesian inference to provide full posterior distributions for model parameters, enabling the comprehensive uncertainty quantification and robust inference of predictor effects. This allows for more transparent interpretation of variable importance, probabilistic classification of damage states, and risk-informed decision-making under conditions of limited or noisy data. Comparison of the two approaches reveals both shared and stage-dependent effects of predictor variables. While the independent failure model supports a mechanistic understanding of discrete failure pathways, the progressive failure model captures escalation dynamics and identifies attributes associated with transitions into higher damage states. Together, these models offer complementary insights and contribute to performance-based wind engineering by linking observed damage patterns to underlying structural and environmental characteristics, supporting improved fragility modeling, regional risk assessment, and resilience-focused design guidance.

Speaker



Jordan Nakayama

PhD Candidate | Auburn University

ID 704: Computationally Efficient Estimation of Bayesian Model Evidence Using Adaptive Likelihood Levels

10:30 AM – 10:50 AM

Author(s): Subhayan De, Northern Arizona University; Reza Farzad, University of Notre Dame; Patrick Brewick, University of Notre Dame; Erik Johnson, University of Southern California; Steven Wojtkiewicz, Clarkson University

In computational mechanics, numerous candidate models are frequently employed to represent complex physical systems, which necessitates a robust framework for model comparison. Bayesian model selection offers a principled approach based on experimental data. However, its practical application is severely hindered by the high computational cost associated with evaluating the marginal likelihood (a.k.a. the model evidence), a multidimensional integral over the model parameter space. To alleviate this issue, this work presents efficient methodologies for estimating the marginal likelihood by reformulating it as a one-dimensional integral evaluated through numerical quadrature over adaptively selected iso-likelihood contours. Three different algorithms are developed to efficiently estimate the quadrature using importance sampling, stratified sampling, and Markov chain Monte Carlo techniques. The proposed approaches are demonstrated on numerical examples and when compared with standard Monte Carlo, nested sampling, and MultiNest methods, show high accuracy and computational efficiency.

Speaker



Subhayan De

Assistant Professor | Northern Arizona University

ID 903: Development of reliability-based experimental loading protocols for steel structures to support performance-based wind engineering

10:50 AM – 11:10 AM

Author(s): James Ban, University of Michigan; Srinivasan Arunachalam, Verisk; Seymour Spence, University of Michigan

Performance based wind engineering (PBWE) requires the validation of structural components when experiencing nonlinearity, particularly connections in steel structures that are often assumed to remain undamaged. However, there is minimal empirical data validating how steel connections behave under wind-induced cyclic loading, especially when significant inelastic member behavior occurs. Current loading protocols used to test steel connections often rely on deterministic cyclic loading histories developed for seismic applications, which fail to accurately capture wind-induced responses. To address this discrepancy, this work proposes a novel framework to generate displacement-controlled experimental loading protocols derived from stochastic wind excitations. Specifically, the target reliability descriptions suggested in ASCE 7-22 are mapped to quantitative limit states for steel structures, such as first yielding, buckling, and fracture. Subsequently, a comprehensive reliability analysis is performed through nonlinear dynamic analysis, considering uncertainties in both wind load and structural model parameters. Unlike traditional reliability analyses, the framework isolates the specific subset of realizations where the quantitative limit states occur. The interstory drift time histories from these critical realizations are extracted and processed using singular value decomposition. This dimensionality reduction technique identifies the dominant features of the response, specifically the first mode, to construct a representative, displacement-controlled loading protocol. The framework is demonstrated through by identifying loading protocols for testing of bolted connections based on the analysis of two 10-story two-dimensional steel braced frames extracted from a three-dimensional archetype building. Two distinct protocols were developed to separately capture alongwind and acrosswind responses. Results indicate that the generated protocols successfully reproduce the limit states associated with ASCE 7-22 reliability targets. This study provides a methodology for generating wind-induced loading protocols, bridging a critical gap in validation for PBWE.

Speaker



James Ban

Mr. | University of Michigan

ID 938: Probability-based residual displacement estimation of nonlinear hysteretic systems subject to seismic loads

11:10 AM – 11:30 AM

Author(s): Lianxu Zhou, University of California Davis; Michele Barbato, University of California Davis

Nonlinear hysteretic systems can exhibit considerable residual displacements after intense seismic loadings. These residual displacements often control the remaining structural capacity and the functionality of a structural system after an earthquake event, represent essential elements in post-earthquake decision-making, and are regarded as critical damage indicators or engineering demand parameters in seismic fragility, loss, and resilience assessment of structures such as bridges and buildings. In such an assessment, the residual displacements should be quantified through a conditional exceedance probability, describing a probability that the residual displacement exceeds a threshold associated with a damage limit state under a given ground motion intensity measure (IM), which can traditionally be generated using cloud-based analysis or incremental dynamic analysis (IDA). However, the classic cloud method can produce inaccurate conditional exceedance probability estimates for residual displacements because its basic assumptions are usually violated. In particular, residual displacements do not typically follow a lognormal distribution, and the residual errors of the regression model between residual displacement and IM in the logarithmic space do not follow a normal distribution. IDA generally provides accurate estimates of residual displacement's conditional exceedance probabilities; however, it usually involves a significant computational effort, especially for a finer IM discretization. To address this issue, this study proposes a new probability-based approach to estimate the residual displacement of nonlinear hysteretic systems based on a probabilistic model of the residual displacement ratio, which is defined as the ratio between the residual displacement and the maximum possible residual displacement of the nonlinear system for a given earthquake record. The proposed method is illustrated through a single-degree-of-freedom system with a bilinear hysteretic constitutive model, is validated using the IDA method, and is compared with the cloud-based method. The analysis results show that the proposed method balances accuracy and computational cost, providing an accuracy similar to that of IDA, but at a significantly lower computation cost that is comparable to that of cloud analysis.

Speaker



Lianxu Zhou

Postdoc | UC Davis

MS 099: Computational Generalized Continua, Gradients, and Nonlocal Mechanics

9:30 AM – 11:30 AM | Location: HUMN 1B80

Chair(s): Richard Regueiro; Remi Dingreville; Alexander Dummer; Christian Linder; Nathan Miller; Matthias Neuner; Leong Hien Poh

Moderators



Alexander Dummer

Dr. | University of Colorado Boulder

ID 15: Computational approaches for Predicting Thermomechanical Responses in Friction Stir Welding of Aluminum Plates

9:30 AM – 9:50 AM

Author(s): Surendra Bhatta, School of Civil and Environmental Engineering, University of Connecticut, Storrs, CT 06269, USA.; Kim Jeongho, School of Civil and Environmental Engineering, University of Connecticut, Storrs, CT 06269, USA.; Sayed A Niknam, Department of Industrial Engineering, Western New England University, Springfield, MA 01119, USA.; Haoyu Wang, Department of Manufacturing & Construction Management, Central Connecticut State University, New Britain, CT 06050, USA.; Ralph Shortt, Advanced Manufacturing LLC, East Hartford, CT 06032, USA.; Dongsheng Li, Advanced Manufacturing LLC, East Hartford, CT 06032, USA.

This presentation addresses a computationally efficient framework for modeling Friction Stir Welding (FSW) by integrating high-fidelity thermomechanical simulations with data-driven surrogate modeling. A Coupled Eulerian–Lagrangian (CEL) approach simulates the thermo-mechanical behavior of FSW, capturing material flow in the Eulerian workpiece and asymmetrical heat distribution caused by the Lagrangian-modeled tool. In addition, a purely Lagrangian analytical heat-input model is developed, and its temperature predictions are validated against CEL simulations and experimental measurements. For mechanical analysis, the model is extended using an implicit integration scheme to compute residual stresses and distortions under unclamped cooling conditions. The predicted distortions show good agreement with experimental observations.

Due to its computational efficiency, the analytical model is further utilized for a parametric study across 30 different combinations of transverse speeds (100–500 mm/min) and rotational speeds (500–1750 rpm). The resulting thermal and mechanical responses such as temperature distributions, residual stresses, and distortions are used to train surrogate models with high predictive accuracy ($R^2 = 0.99$). This provides a reliable tool for design space exploration and process optimization in FSW within the considered parameter range.

Keywords: Friction Stir Welding, Coupled Eulerian–Lagrangian, Finite Element Methods, Surrogate Modeling

Speaker



Surendra Bhatta

ID 235: Nonlocal Dislocation-based Plasticity Incorporating Micromorphic Approach

9:50 AM – 10:10 AM

Author(s): George Z Voyiadjis, Louisiana State University; Ahmad J. Aljaafreh, Louisiana State University

The effect of material microstructure on size effects and strain localization phenomena in metals is well-documented and experimentally observed; however, classical local plasticity theories, which define the constitutive equations at the material-point level, do not reflect the effect of the material microstructure in plastic behavior and cannot represent spatial interactions (nonlocal behavior) due to microstructures and nonuniform plastic flow.

This contribution presents the theoretical development of a model representing mixed isotropic–kinematic hardening by adapting a small-strain micromorphic generalized-continuum approach based on the methodology suggested by (Forest, 2009; Maugin, 1999; Voyiadjis & Faghihi, 2013). Balance equations in strong and weak forms are introduced, and a thermodynamically consistent formulation model is developed for the yield function and the evolution of the internal variables.

The formulation includes macro-fields of the kinematic (strain-like deviatoric tensor) and isotropic (accumulated plastic strain) hardening, with their independent micromorphic counterparts. The generalized principle of virtual power yields the standard macroscopic equilibrium, along with additional microforce balance equations for the micromorphic fields.

Enforcing the Clausius–Duhem inequality to derive state laws and residual dissipation, a quadratic Helmholtz free energy is proposed comprising classical elastic energy, hardening contributions, penalty terms that couple the macro and micromorphic internal variables, and gradient contributions carried by micromorphic stresses. The thermodynamic forces associated with the state variables are then derived.

The microforce balance equations corresponding to the micromorphic variables are used to produce Helmholtz-type partial differential equations that define the internal variables and help in nonlocal regularization. Incorporating intrinsic length scales from ratios of energetic moduli associated with coupling and gradient terms. One of the key concepts to develop advanced models in plasticity is incorporating an intrinsic length scale (Voyiadjis & Faghihi, 2013) to capture the material behavior and account for microstructure characterization. The length scale of each hardening type is introduced as a parameter that represents intrinsic microstructural lengths, such as grain size. Presenting the length scale in the constitutive equations provides consistency in units and helps to illustrate the difference in behavior between materials.

Finally, the main contribution is the introduction of intrinsic length scales, physically based on dislocation-density measures corresponding to statistically stored dislocations (SSDs) and geometrically necessary dislocations (GNDs). This is relevant to micron-scale metallic structures (e.g., MEMS components and microfabricated test coupons), and can be calibrated/validated using FIB-fabricated micropillars/micro-cantilevers with in-situ SEM mechanical testing.

References

Forest, S. (2009). Micromorphic Approach for Gradient Elasticity, Viscoplasticity, and Damage. <https://doi.org/10.1061/ASCE0733-93992009135:3117>

Maugin. (1999). Thermomechanics of nonlinear irreversible behaviors

Voyiadjis, G. Z., & Faghihi, D. (2013). Gradient plasticity for thermo-mechanical processes in metals with length and time scales. *Philosophical Magazine*, 93(9), 1013–1053. <https://doi.org/10.1080/14786435.2012.740576>

Speaker



George Voyiadjis

Boyd Professor | Louisiana State University

ID 254: An FFT-based Method for Micropolar Field Dislocation and Disclination Mechanics

10:10 AM – 10:30 AM

Author(s): Noah Francis, Sandia National Laboratories; Rémi Dingreville, Sandia National Laboratories; Stéphane Berbenni, Université de Lorraine

This work describes the implementation of Field Dislocation and Disclination Mechanics (FDDM) in Cosserat/Micropolar linear elasticity using the Fast Fourier Transform (FFT)-based method. Micropolar mechanics is an appropriate setting for the mechanics of dislocations and disclinations due to how it is naturally modeled by incompatible strains. On one hand, dislocations can be seen as the result of incompatibility of the first strain tensor (whose symmetric part equals the classical small strain tensor) encoding a translational discontinuity; and on the other hand, disclinations can be seen as the result of incompatibility in the second strain tensor (related to curvature) encoding a rotational discontinuity. We numerically resolve grain boundary problems with anisotropic crystals by imposing dislocation/disclination density fields as a body force or eigenstrain using the FFT-based method. The FFT-based method is a popular alternative to the Finite Element Method in the case of periodic composite/polycrystal problems, due to algorithmic speed and the use of a pixelized/voxelized image rather than a mesh. In this setting, our simulations are confined to a prescription of either the average Micropolar stresses or the average Micropolar strains. An important aspect of this work is the calibration of the Micropolar elastic constants via Molecular Dynamics (MD), and the model's validation when compared to various MD simulations. Lastly, a novel piece of our approach is the supertensor formalism, in which similar tensors are grouped together into objects called supertensors. For example, the two Micropolar strain tensors are placed together in the strain supertensor (visually this looks like a column vector with the tensors as entries). This formulation has been found to give organizational clarity to the (sometimes unwieldy) equations on paper and in the code. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525. (SAND2026-15899A).

Speaker



Noah Francis

Postdoc | Sandia National Laboratories

ID 312: A Conservative Probabilistic Framework for Damage Evolution via Doob's h-Transform

10:30 AM – 10:50 AM

Author(s): Upadhyayula M M Aditya Sai Gopal, Indian Institute of Science, Bangalore; Ved Prakash, Indian Institute of Science, Bangalore; Ananth Ramaswamy, Indian Institute of Science, Bangalore; Debasish Roy, Indian Institute of Science, Bangalore

Continuum Damage Mechanics (CDM) provides a widely adopted framework for modeling crack initiation and propagation in solids through phenomenological damage variables that represent material degradation. While successful in many applications, classical CDM formulations often rely on ad hoc evolution laws and face challenges related to irreversibility, localization, mesh dependence, and thermodynamic consistency. With the motivation of addressing these issues and considering the random nature of damage, our earlier work introduced the probabilistic damage model FeynKrack, in which damage evolution is linked to the evolution of transition probability densities of an underlying stochastic killed diffusion process. This formulation was motivated by a mathematical analogy between degradation functions in CDM and Radon–Nikodym derivatives in stochastic processes.

In the original FeynKrack formulation, damage evolution was modeled as a killed diffusion process inspired by the Feynman–Kac formalism. The killing term represents progressive material degradation and leads to a monotonic loss of probability mass with increasing mechanical loading. While this approach provides a natural probabilistic interpretation of damage accumulation and irreversibility, the resulting non-conservative evolution complicates thermodynamic interpretation and limits direct connections with conservative continuum mechanics frameworks.

In this work, we extend the FeynKrack framework by reformulating the non-conservative killed diffusion into a conservative stochastic process using Doob's h-transform. The transformation eliminates the killing term while preserving its effect through a modified drift term, thereby ensuring conservation of probability mass. In this reformulated description, damage is no longer associated with a loss of probability, but is instead encoded in the altered transport dynamics of the stochastic process. This shift enables a conservative evolution that is more naturally aligned with thermodynamic principles while retaining the essential features of damage accumulation and irreversibility. The resulting conservative formulation is more suitable for utilizing standard probabilistic frameworks.

The proposed formulation is demonstrated through numerical simulations of a uniaxial compression test with a pre-existing inclined notch, a standard benchmark for damage localization and crack initiation. The results show that the reformulated model successfully reproduces localized damage patterns consistent with fracture experiments, while admitting a conservative evolution of the underlying probability density. Overall, this work provides a mathematically consistent and physically grounded representation of damage evolution, establishing a clear link between probabilistic fracture modeling and conservative continuum mechanics. The proposed reformulation provides a robust foundation for further developments in stochastic and variational approaches to damage and fracture.

Speaker



Upadhyayula M M Aditya Sai Gopal

Mr. | Indian Institute of Science, Bangalore, India

ID 363: Internal Length Scale in Continuum Field Theories: Regularization of Strain Softening in Cauchy's Classical and Eringen's Micropolar Continua

10:50 AM – 11:10 AM

Author(s): Madura Pathirage, University of New Mexico

Classical Cauchy continuum mechanics assumes material homogeneity, which precludes the characterization of microscopic scales in its balance laws. This fundamental limitation, together with the use of local constitutive equations for strain softening behavior, leads to localization problems that are mathematically ill-posed where numerical solutions to the governing differential equations exhibit mesh-dependence upon spatial discretization. Different continuum theories have emerged to address this deficiency; one notable example is Eringen's micropolar continuum, which introduces an internal length scale through the presence of independent rotational degrees of freedom and couple stresses. This internal length provides regularization for problems dominated by shear band formation. However, micropolar theory fails to regularize pure mode I fracture, indicating that the addition of rotational kinematics alone is insufficient for complete regularization across all failure modes. This work reconsiders the foundational structure of Cauchy's classical and Eringen's micropolar continuum theories through first principles, examining the assumptions underlying their formulation. We develop a unified continuum framework within which the existing classical and micropolar formulations emerge as special cases of a broader theoretical structure. By systematically extracting internal length parameters from this unified framework, we establish a new approach to regularization and more generally to continuum mechanics with internal length. Applying this framework to strain softening and localized deformation, we demonstrate that a properly incorporated internal length scale fully regularizes the ill-posed problem in classical Cauchy continuum and resolves the lack of mode I failure regularization in micropolar continuum. The framework clarifies how internal lengths should be incorporated to restore mathematical well-posedness and to account for the microscopic heterogeneous structure. We also discuss some applications to other domains within the vast field of continuum mechanics, providing a unified mathematical perspective on the fundamental role of internal length scales in continuum field theories.

Speaker



Madura Pathirage

Assistant Professor | University of New Mexico

ID 452: A Phase-Field Cohesive Zone Framework for Frequency-Dependent Fatigue in Quasi-Brittle Materials

11:10 AM – 11:30 AM

Author(s): RAJEEV KUMAR RANJAN, INDIAN INSTITUTE OF SCIENCE, BANGLORE, INDIA; Ananth Ramaswamy, INDIAN INSTITUTE OF SCIENCE, BANGLORE, INDIA

The fatigue behaviour of quasi-brittle materials is affected by the loading frequency applied. While existing fracture and fatigue models often account for stress amplitude and loading history, the explicit role of loading frequency in damage accumulation and crack propagation is not well understood within most phase-field or cohesive zone formulations.

In this study, a thermodynamically consistent phase-field cohesive zone model (PF-CZM) is developed to analyse frequency-dependent fatigue damage in quasi-brittle materials. The proposed phenomenological PFCZM formulation incorporates a fatigue degradation law that directly influences damage evolution in response to loading frequency. It encompasses a description of stiffness degradation, crack initiation, and fatigue characteristics under cyclic loading at different frequencies.

Numerical simulations are studied on notched beams subjected to three-point bending under constant-amplitude cyclic loading over a range of loading frequencies. The findings of this study show a clear frequency-dependent fatigue behaviour, with increasing frequency leading to slower damage accumulation and delayed crack initiation. The simulated results are validated with the experimental results and show a good agreement in terms of fatigue life and stiffness degradation. The predicted trends highlight the role of frequency as an intrinsic parameter governing fatigue degradation, independent of load amplitude.

The proposed PF-CZM framework offers a physically consistent and computationally efficient tool for capturing frequency effects in the fatigue fracture of quasi-brittle materials, thereby improving predictive capability for structures subjected to cyclic loading at various rates.

Speaker



Rajeev Kumar Ranjan

INDIAN INSTITUTE OF SCIENCE, BANGLORE, INDIA

MS 094: Mechanics and Physics of Granular Materials

9:30 AM – 11:30 AM | Location: VAC 1B20

Chair(s): Ryan Hurley; Marcial Gonzalez; Yimin Lu; Dawa Seo; Alessandro Rotta Loria; Ali Daouadji

Moderatorss



Anthony Rosato

Professor | New Jersey Institute of Technology



Anil Misra

Professor and Chair | Florida International University

ID 949: Statistical Shape-Size Coevolution in Crushable Granular Solids: A Continuum Thermodynamics Framework

9:30 AM – 9:50 AM

Author(s): Divyanshu Lal, Northwestern University; Giuseppe Buscarnera, Northwestern University

Particle size dispersion is widely recognized as a key factor for the crushability of granular materials. However, emerging evidence indicates that distributed grain fracture induces concurrent shape alterations, fundamentally modifying the statistics of the fragment morphology and driving their evolution toward thermodynamically favorable shape attractors. This study develops a continuum thermodynamic framework to characterize the mechanical consequences of coupled size-shape evolution during the confined comminution of crushable granular solids. Unlike conventional approaches that neglect the particle shape, the proposed formulation captures shape evolution statistically through synthetic descriptors of morphological dispersion embedded within the continuum-scale constitutive properties. Statistical distributions of shape indicators, specifically flatness and elongation ratios, are incorporated into the free energy and dissipation potentials of Continuum Breakage Mechanics, with their evolution governed by a coevolution law linking shape transformation to size reduction through a morphological rate parameter. The model predicts non-monotonic trends in crushing strength as a function of evolving shape distributions, with the response strongly dependent on initial morphology and proximity to attractor states. This behavior reveals optimal shape configurations that maximize the crushing resistance. Additionally, assemblies dominated by elongated and platy particles exhibit enhanced stiffness and elevated energy dissipation capacity. Validation against discrete element simulations and laboratory measurements corroborates the framework's predictive capability, establishing shape dispersion as a thermodynamically consistent state variable for granular continua. These findings offer new mechanistic insights into the complex behavior of natural and engineered granular systems governed by collective particle breakage.

Speaker



Divyanshu Lal

PhD student | Northwestern University

ID 522: Tuning entanglement and strength in staple-like granular materials through particle geometry and mechanical vibrations

9:50 AM – 10:10 AM

Author(s): Saeed Pezeshki, University of Colorado Boulder; Youhan Sohn, University of Colorado Boulder; Francois Barthelat, University of Colorado Boulder

Entangled granular material produce unusual and attractive properties and mechanisms not seen in conventional granular materials: unique combinations of high tensile strength and toughness, capabilities for reversible assembly and disassembly enabling full recyclability, and damage tolerance. While some of these attributes and mechanisms share some traits with traditional granular materials, few studies have focused on entanglement and strength. In this work we focused on U-shaped, staple-like particles. We first focused on the effect of particles geometry by adjusting the angle between the legs and the crown (crown-leg angle). Our tensile experiments and discrete element models on large entangle bundles of these particles show competing mechanisms between entanglement strength and geometric engagement between particles, giving rise to an optimum crown-leg angle that maximizes the tensile strength of the bundle. We also show that tensile forces are transmitted by a small fraction of the staples, which is organized in only a few force chains. The formation and breakage of these chains is however highly dynamic: as force chains break, they are replaced by fresh ones which were previously mechanically invisible. In the second part of this study, we investigated the combine effects of the mechanical vibrations and particles geometry on entanglement, tensile force-chain networks, tensile strength and deformability. Both experiments and simulations demonstrate a strong correlation between entanglement density and the tensile strength of the bundle. Our results reveal that prolonged vibrations increase the entanglement density up to a steady state value, at which point the rate of entanglement equals the rate of disentanglement. Vibrations can be also used to heal entangled bundles: Large defects within the bundle, several times the particle size, can be completely repaired through mechanical vibration under confinement. Conversely, when the confinement is removed, we show that vibrations can completely and rapidly disassemble entangled bundles into individual particles, offering interesting perspectives in terms of reconfigurability, recyclability, as well as programmable assembly and disassembly.

This work was supported by the US National Science Foundation (Mechanics and Materials and Structures, Award No. 2033991, Award No. 2517927).

Speaker



Saeed Pezeshki

PHD Student | University of Colorado Boulder

ID 1034: Numerical Quantification of Scale Effects in Non-standard Subsurface Installations interacting with Shear Bands

10:10 AM – 10:30 AM

Author(s): Dawei Xue, Tongji University; Giuseppe Buscarnera, Northwestern University

The interaction between geotechnical structures and finite plastic shear zones influences the capacity and performance of these systems, particularly in non-standard or reduced-scale installations with miniaturized components. This paper investigates these scale effects numerically using implicit gradient-enhanced and gradient-type nonlocal plasticity models, including a hardening–softening non-associative Mohr–Coulomb constitutive law augmented with an over-nonlocal formulation, which enables closed-form expressions of the shear band thickness dictated by the soil microstructure. Within this framework it is possible to quantify the scale effects arising from the ratio between the system size and the shear zone thickness, with numerical studies covering specimens under plane strain compression, miniaturized plate anchors, and shallow footings. The simulations, validated by DEM data, 1g tests, and centrifuge tests, show that decreasing model or system size leads to an upward shift of the capacity curves, higher load-bearing capacities, weaker strength loss upon deformation, and systematic thickening, shortening, or diffusion of plastic and shear zones. These effects depend on the system size relative to the intrinsic material length scale and may transition from strain localization to diffuse plastic zones as the dimensions of tested system decrease. Finally, corrective or re-scaling factors based on the shear band thickness–to–structure size ratio are introduced to facilitate the prediction and re-scaling of pullout or bearing capacity for reduced-scale or non-standard geotechnical systems, for which such scale effects are expected to be more prominent.

Speaker



Giuseppe Buscarnera

Professor | Northwestern University

ID 167: Micromechanical origins of morphology-dependent shear behavior in coral sands: A 3D in-situ analysis

10:30 AM – 10:50 AM

Author(s): Ruidong Li, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China; Zhen-Yu Yin, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China

Coral sand, as a representative marine granular material, is ubiquitous across tropical and subtropical areas and constitutes the foundational substrate for offshore infrastructure. Despite its critical engineering role, the mechanical behavior of this biogenic geomaterial remains poorly understood, primarily due to its extreme morphological irregularity and pervasive intra-particle pore structures. These characteristics fundamentally challenge classical granular mechanics, as the highly non-convex geometries and internal voids deviate markedly from idealised assumptions of particle shape and integrity. Consequently, the mechanical roles of specific grain morphologies are obscured within naturally heterogeneous mixtures, impeding the establishment of a clear mechanistic link between grain-scale physics and macroscopic constitutive response of coral sands.

To address this scientific gap, an advanced experimental program was implemented by integrating high-resolution X-ray micro-computed tomography (μ CT) with an in-situ mini-triaxial testing apparatus. Natural coral sand was systematically segregated into three morphological sub-assemblies, classified as compact-shaped, platy-shaped, and branch-shaped particles, allowing the intrinsic mechanical signature of each morphology to be isolated under controlled triaxial loading. Grain-scale kinematics, contact fabric evolution, particle breakage, and pore network evolution were quantified using a state-of-the-art three-dimensional (3D) image analysis pipeline that combines a large vision model for particle segmentation with optimal transport-based particle tracking. This automated framework is applicable to arbitrarily complex particle morphologies and facilitates high-fidelity characterisation, even for highly irregular and porous biogenic grains.

The micro-mechanical analysis suggests that particle morphology dictates the macroscopic response through divergent granular mechanics pathways and breakage modes. Branch-shaped particles exhibit superior peak shear strength facilitated by intense geometric interlocking, where the protrusions of adjacent grains create a robust but unstable skeletal framework characterized by high coordination numbers and strong force chain networks. However, this strength is ephemeral as the slender branches are highly susceptible to catastrophic tensile splitting, leading to a sudden redistribution of contact forces and suppressed dilatancy. In contrast, the behavior of platy particles is governed by a sliding-and-stacking mechanism. These grains undergo significant rotation and preferential fabric alignment perpendicular to the principal stress direction, resulting in substantial volumetric contraction and a ductile failure mode dominated by edge chipping. Compact particles, possessing lower aspect ratios, maintain a more stable contact network with progressive crushing, bridging the gap between the extreme behaviors of branch and platy geometries.

The primary contribution of this research lies in providing a fundamental physical basis for understanding how skeletal geometries dictate the destruction of the grain skeleton through differentiated fabric evolution. By establishing a direct link between 3D particle kinematics and the stability of the granular assembly, this study offers essential benchmarks for the refinement of multiscale constitutive theories. These insights into morphology-dependent micromechanics significantly enhance the capability to predict the long-term stability of marine infrastructures by integrating biogenic complexity into the modern framework of granular physics.

Speaker



Ruidong Li

PhD student | The Hong Kong Polytechnic University

ID 183: A DEM-DFM Coupled Framework for Thermo-Hydro-Mechanical-Chemical Modelling of Methane Hydrate-Bearing Sediments

10:50 AM – 11:10 AM

Author(s): Chengkai XU, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China; Zhen-Yu YIN, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong, China; Pei WANG, Institute of Geotechnical Engineering, School of Civil Engineering and Architecture, East China Jiaotong University, Nanchang, Jiangxi, China

Methane hydrate-bearing sediments (MHBS) are widespread in deep marine and permafrost settings and are increasingly considered a strategic, lower-carbon energy resource. Gas production from MHBS, however, is governed by tightly coupled thermal-hydraulic-mechanical-chemical (THMC) processes. Depressurization is one of the most economical field strategy that reduces pore pressure to destabilize hydrate, releasing methane and water while creating pressure gradients that drive multiphase flow toward the well. Yet hydrate also cements the granular skeleton; its dissociation can erode load-bearing capacity, trigger compaction and localization, mobilize fines, and elevate risks of wellbore instability, sand production, and even slope failure. Continuum simulations have illuminated macroscopic evolutions of pressure, temperature, saturation, permeability, and deformation, but they homogenize the skeleton and hydrate, limiting resolution of particle-scale mechanisms that control contact reconfiguration, pore connectivity, channelization, and erosion during production. This work presents a micro-mechanically informed, coupled THMC framework that integrates a Dynamic Fluid Mesh (DFM) for multiphase reactive flow and heat transport with a Discrete Element Method (DEM) for sand-hydrate mechanics. Hydrate is modeled explicitly as particles or bonded clusters within pores and at grain contacts, enabling dissociation, debonding, migration, and erosion to be resolved at the particle scale while remaining strongly coupled to pressure, capillarity, and temperature via reaction kinetics. DFM constructs dynamic tetrahedral meshes from sand-particle centroids (Delaunay triangulation) to compute porosity, phase saturations, and permeability at the pore scale. Two-phase Darcy flow and an energy balance with convective transport and endothermic dissociation are solved using finite-volume schemes. Gas compressibility (via an equation of state) and capillary relations (van Genuchten-Mualem) enforce local mass conservation. Fluid-particle coupling applies pressure forces to sand grains and porosity-dependent drag to hydrate particles, while DEM contact laws include rolling resistance for sand-sand contacts and soft bonds for hydrate-sand/hydrate-hydrate cementation. Fields (pressure, temperature, saturations, permeability) and mesh topology are iteratively updated, achieving strong two-way coupling through evolving porosity-permeability and fluid-particle interaction forces. Validation against depressurization experiments reproduces hallmark signatures: rapid cooling with subsequent recovery, an early dissociation-rate peak, mass-balanced hydrate loss dominated by dissociation, and compaction-driven strain. Parametric studies show that stronger depressurization accelerates dissociation and permeability growth but deepens cooling and enhances deformation; stepwise depressurization moderates these trade-offs. Higher ambient temperature shortens the cooling phase, smooths dissociation, reduces mixed-contact persistence and clogging, and promotes cleaner channelization with earlier hydraulic stabilization. Overall, the DEM-DFM framework links particle-scale contact mechanics and fines dynamics to field-scale flow capacity and stability, providing a physics-based tool to design pressure-temperature protocols that enhance gas recovery while mitigating geomechanical and sand-production risks in heterogeneous MHBS reservoirs.

Speaker



Xu Chengkai

PhD Student | The Hong Kong Polytechnic University

ID 931: A Framework for Extracting Basic Soil Moduli from Undrained Cyclic Triaxial Responses

11:10 AM – 11:30 AM

Author(s): Qinlin Yu, University of Colorado Boulder; Srikanth Madabhushi, University of Colorado Boulder

This paper presents a framework for directly extracting basic elastic and elastoplastic moduli from undrained cyclic triaxial test responses, with particular emphasis on their evolution toward liquefaction. The proposed approach enables a clear separation of elastic and elastoplastic strain components through the definition of an elastic strain wedge, allowing the direct computation of shear and bulk elastic moduli as well as elastoplastic hardening and dilatancy moduli from measured stress-strain-pore pressure responses. This provides a novel alternative to conventional indirect inference of moduli for constitutive model calibration.

Measured undrained cyclic triaxial test data on F65 Ottawa sand from LEAP reference experiments are first processed using a constrained fitting approach developed to address increased signal noise encountered near and during liquefaction. Conventional frequency-domain and wavelet-based filtering techniques were found to be ineffective across the full response range. Instead, fitting functions subject to constraints at cycle endpoints and stress reversals are employed to preserve key mechanical features of the response. The fitted results show good agreement with the original measurements throughout the liquefaction process and enable robust and repeatable extraction of basic moduli. Sensitivity analyses demonstrate that while the assumed elastic wedge thickness influences the absolute magnitude of the extracted elastic moduli, it does not affect the observed trends or cyclic characteristics of either elastic or elastoplastic components.

The extracted moduli reveal distinct and physically interpretable behaviors. Elastic moduli generally decrease with progressive cycling toward liquefaction, with evidence of cyclic stiffening immediately following shear stress reversals. By contrast, elastoplastic hardening and dilatancy moduli exhibit more stable overall magnitudes accompanied by pronounced cyclic fluctuations, reflecting alternating plastic contraction and dilation during cyclic loading. When represented in alternative stress spaces, all basic moduli display characteristic valley structures, with stiffening occurring at the start of each cycle following stress reversal. The boundaries of these valleys are closely related to critical-state stress ratios, with hardening and dilatancy moduli exhibiting butterfly-shaped trajectories within these limits. Overall, these observations highlight systematic and repeatable trends in the evolution of elastic and elastoplastic moduli that are not readily apparent from conventional stress-strain interpretations alone.

Speaker



Qinlin Yu

University of Colorado Boulder

Lunch Break

11:30 AM – 1:00 PM

Lunch tent #1

11:30 AM – 1:00 PM

Lunch tent #2

11:30 AM – 1:00 PM

Mechanics of Pavements committee meeting

11:45 AM – 12:45 PM | Location: UMC 247

Student Competition Awards Ceremony

11:45 AM – 12:45 PM | Location: CHEM 140

Keynote: Grains-in-motion: from x-ray rheography to heterarchical granular dynamics

1:00 PM – 2:00 PM | Location: UMC - Glenn Miller Ballroom

Grains-in-motion: from x-ray rheography to heterarchical granular dynamics

Itai Einav, Ph.D.

Professor

Director of the Sydney Centre in Geomechanics and Mining Materials (SciGEM)

University of Sydney

Abstract: Bulk materials, often in granular form, underpin a wide range of industries and scientific fields, from minerals engineering and pharmaceuticals to batteries, geophysics, and geotechnology. Far from static, these systems are inherently dynamic, and understanding their motion is key to both process performance and fundamental science. In recent years, my team and I have developed a distinctive capability in this space, advancing the science of grains-in-motion.

This talk highlights two developments that translate fundamental insights into practical tools. First, DynamiX, a world-unique simultaneous three-way X-ray imaging system, enables X-ray rheography, a new method for measuring three-dimensional internal motion in granular systems. Second, heterarchical granular dynamics introduces a computational framework for modelling complex particulate systems. It enables tracking of arbitrary grain-size distributions across large systems and overcomes key limitations of conventional discrete element methods.

Together, these approaches provide experimentally validated, quantitative access to bulk material dynamics across scales, supporting improved modelling, design, and optimisation of particulate processes.

Biosketch: After completing his PhD at the Technion, Israel, in 2002, Itai Einav moved to the University of Western Australia for his postdoc. In 2005, he joined the University of Sydney as a Senior Lecturer and was promoted to Full Professor in 2012. While in Sydney, he has served as the Director of the Sydney Centre in Geomechanics and Mining Materials (SciGEM). His research is guided by a passion for bridging physics and engineering. This interdisciplinary focus has enabled him to make significant contributions across both domains while developing a versatile toolkit of theoretical, computational, and experimental methods. Building on this foundation, Itai has advanced research in areas such as geomechanics, granular physics, geophysics, solid and fluid mechanics, and minerals processing, as well as in interdisciplinary collaborations at the interface with the arts.

Speaker



Itai Einav

Professor and Director of SciGEM | The University of Sydney

Moderators



Yida Zhang

Associate Professor | University of Colorado Boulder

MS 015: Digital and sensing technologies for smart monitoring of infrastructure and buildings

2:15 PM – 3:35 PM | Location: HUMN 250

Chair(s): Bryan G. Pantoja Rosero; Shenghan Zhang; Salvatore Salamone; Matthew DeJong

Moderatorss



Bryan Pantoja Rosero

Prof. | Nanyang Technological University, Singapore



Shenghan Zhang

Prof. | Hong Kong University of Science and Technology (HKUST)

ID 766: Post-Earthquake Damage Assessment via Uncertainty-Aware Fusion of Heterogeneous Sensing Data

2:15 PM – 2:35 PM

Author(s): Sudaο He, Hong Kong University of Science and Technology; Shenghan Zhang, Hong Kong University of Science and Technology

Post-earthquake damage assessment is critical for ensuring public safety and facilitating timely recovery, yet it remains challenging. While advanced sensing, ranging from UAVs and fiber-optic sensors, provide rich data, inferring component-level and structure-level damage from partial, heterogeneous observations is difficult. This study introduces two novel deep learning frameworks designed to bridge these gaps by integrating diverse data modalities while explicitly quantifying prediction uncertainty.

First, we propose a Dynamic Multimodal Posterior Network (DMPN) for component-level assessment. This model fuses distributed strain data and surface crack patterns to estimate damage in reinforced concrete shear walls. Second, at the structure level, we present an Uncertainty-Aware Heterogeneous Graph Attention Network (UHGAN). This framework organizes structural components into a heterogeneous graph, integrating acceleration data, and component damage.

Computational studies on simulated RC shear walls and frames demonstrate that both methods yield satisfactory accuracy, even under incomplete data conditions. The results confirm that integrating multi-modal data with explicit uncertainty quantification offers a viable solution for next-generation structural health monitoring and post-earthquake assessment.

Speaker



Shenghan Zhang

Prof. | Hong Kong University of Science and Technology (HKUST)

ID 799: Autonomous Mobile Robotic System for Real-Time Crack Detection and 3D Profiling for Automated Repair

2:35 PM – 2:55 PM

Author(s): Yong Voeurn, Georgia Southern University; Emmanuella Ogun, Georgia Southern University; Doyun Lee, Georgia Southern University

The deterioration of civil infrastructure poses a significant threat to public safety and long-term serviceability. Conventional manual inspection methods remain inherently subjective, labor-intensive, and often hindered by limited accessibility, particularly in complex, elevated, or hazardous environments. To address the need for automated, reliable, and actionable maintenance workflows, this study presents an integrated autonomous mobile robotic system capable of simultaneous navigation, high-fidelity crack detection, and precise three-dimensional (3D) crack profiling. The proposed framework is built on a Clearpath Husky Unmanned Ground Vehicle (UGV) equipped with a Yaskawa HC10 six-degree-of-freedom robotic manipulator, operating within a distributed ROS2 software architecture. Environmental perception and localization are achieved using a Hesai 32-channel LiDAR for Simultaneous Localization and Mapping (SLAM), while surface-level visual data are acquired via an Intel RealSense RGB-D camera to enable defect identification. Crack detection is performed through a novel two-stage deep learning pipeline: a U-Net first conducts semantic segmentation to localize potential damage regions, followed by a Pix2Pix conditional generative adversarial network (GAN) that refines these predictions through residual-based enhancement, achieving a mean Intersection over Union (mIoU) of 73.9% and an F1-score of 76.4% on benchmark datasets. To bridge perception and physical intervention, the system integrates an LMI Gocator 2618A laser line profiler. Upon visual detection of a defect, the robotic platform deploys this high-resolution sensor to capture detailed 3D crack profiles, extracting critical parameters such as depth, width, and volume for automated repair. Accurate 3D profiling enables precise crack volume estimation and provides geometric details essential for adaptive robotic path planning and controlled material deposition, ensuring consistent repair quality along complex and irregular crack surfaces. By combining vision-based diagnostics with precise 3D metrology, this work establishes a practical "scan-assess-repair" workflow that provides the accuracy needed for autonomous infrastructure maintenance.

Speaker



Yong Ann Voeurn

PhD Student/RA | Georgia Southern University

ID 827: High Precision Deformation Measurement During Structural Integrity Testing on Nuclear Reactor Containment Building Using a Combined FMCW radar and Accelerometer Sensor

2:55 PM – 3:15 PM

Author(s): Dauri Kim, Korea Advanced Institute of Science & Technology; Jigu Lee, Korea Advanced Institute of Science & Technology; Kiyoung Kim, Korea Advanced Institute of Science & Technology; Hoon Sohn, Korea Advanced Institute of Science & Technology

Structural Integrity Tests (SIT) for nuclear power plants are typically conducted upon completion of construction and subsequently at five-year intervals. However, given the high-risk nature of nuclear facilities—where accident mechanisms are complex and may involve cascading or compound events—periodic inspections alone are insufficient. As the frequency of extreme climate events such as long-term high-temperature phenomena increases, the introduction of continuous monitoring sensors is required. In this regard, reliable measurement of structural displacement in Reactor Containment Buildings (RCBs) is critical for ensuring long-term structural integrity and operational safety.

This work introduces a high-precision fusion-based sensing approach for continuous displacement monitoring of RCBs. As conventional displacement measurement instruments, extensometers and digimatic indicators suffer from following limitations. Extensometers are prone to poor accuracy due to instrument self-weight, hysteresis-induced nonlinearity, and the practical challenges of installing wires up to 150 feet in length for each measuring locations. Digimatic indicators, on the other hand, require assembly of large steel frames inside RCB, which makes the measurement method labor-intensive and cost-consuming.

To overcome these challenges, the proposed system combines measurements from a three-axis MEMS accelerometer with phase information obtained from a millimeter-wave frequency-modulated continuous-wave (FMCW) radar. The integration of these complementary sensing modalities enables substantial improvements in measurement performance, achieving sub-0.1 mm resolution for both static and dynamic displacement responses. The developed sensor platform prioritizes compactness, reliability, and cost-effectiveness. It integrates a 60 GHz radar chipset, a MEMS accelerometer, and a microcontroller supporting multiple communication interfaces. The resulting hardware occupies a small form factor (150 × 150 × 50 mm³), making it well suited for large-scale deployment in nuclear power facilities. Automated optimal target selection mechanism that leverages short-duration initial measurements from both radar and accelerometer sensors identifies the most stable structural reflection points and accurately determines the conversion relationship between radar line-of-sight displacement and true structural motion. Furthermore, accelerometer measurements are used to assist an adaptive phase-unwrapping strategy, effectively resolving radar phase ambiguity and improving displacement estimation robustness. To further enhance accuracy, radar-based displacement measurements are fused with acceleration-derived displacement using a finite impulse response (FIR) filtering approach, reducing noise and drift commonly associated with acceleration integration. Experimental evaluations performed on structural test models demonstrate that the proposed fusion strategy consistently achieves displacement measurement errors below 1 mm.

The developed sensor system offers a reliable solution for continuous displacement monitoring of Reactor Containment Buildings, providing a practical alternative to conventional one-time SIT procedures. The proposed fusion-based sensing framework shows strong potential for application in nuclear power plants, supporting advanced structural health monitoring, predictive maintenance, and improved operational safety.

Speaker



Dauri Kim

Korea Advanced Institute of Science & Technology

ID 834: Multi-Modal Monitoring of a Scour-Critical Bridge Using Sensors and PTZ Imaging

3:15 PM – 3:35 PM

Author(s): Byunghyun Kim, The University of Texas at Austin; Salvatore Salamone, The University of Texas at Austin

Scour is one of the main causes of bridge failure, highlighting the need for continuous and intelligent monitoring of scour-critical structures. This study presents a multi-modal monitoring system deployed on a scour-critical bridge in San Marcos, Texas. The system integrates structural sensors, real-time visual monitoring, and AI-based data processing. The full system was installed in mid-December 2025 and has been collecting data continuously since then.

The monitoring platform includes tiltmeters, crack meters, laser displacement sensors, accelerometers, and a radar-based water-level sensor. All sensors are connected to a solar-powered, cellular-enabled data acquisition system for real-time remote access. In addition, a pan-tilt-zoom (PTZ) camera system is installed to visually monitor critical regions of the bridge substructure.

Using images captured by the PTZ camera, we verified that rapid 3D surface reconstruction of the substructure is feasible using the MapAnything model. The results show that geometry-aware 3D models can be generated directly from in-situ camera data with minimal manual processing. This confirms the potential of PTZ-based vision systems for digital representation of existing infrastructure.

The system has shown stable performance under field conditions, and sensing data are being collected in parallel with visual data. This ongoing deployment provides a valuable dataset that combines structural signal data and evolving 3D geometry. Future work will focus on integrating 3D visual data and sensor data to develop a multi-modal large language model for automated condition assessment and decision support.

Speaker



Byunghyun Kim

University of Texas Austin

MS 008: Advances in AI-enabled Approaches, Robotic Inspection, and Smart Sensing for Civil Infrastructure

2:15 PM – 3:35 PM | Location: HUMN 135

Chair(s): Hadi Salehi; Rih-Teng Wu; Mohammad Reza Jahanshahi; Kenneth J Loh

Moderators



Rih-Teng Wu

Associate Professor | National Taiwan University

ID 180: Digital Twin-Guided Localization and Assistive Navigation for UAS-Based Infrastructure Visual Inspection

2:15 PM – 2:35 PM

Author(s): Yuxiang Zhao, University of Illinois Urbana-Champaign; Martin Xu, University of Illinois Urbana-Champaign; Zhengyu Tao, University of Illinois Urbana-Champaign; Ziyi Rong, University of Illinois Urbana-Champaign; Mohamad Alipour, University of Illinois Urbana-Champaign

Unmanned Aerial Systems (UAS) have shown significant potential for efficient and reliable structural visual inspection and are increasingly adopted for infrastructure condition assessment. Despite these advances, current UAS-based inspection practices still rely heavily on manual planning and control. Challenging structural environments and rising labor costs make such approaches increasingly inadequate for meeting growing inspection demands.

To improve the level of automation in UAS-based infrastructure visual inspection, recent studies have focused on automatically generating optimized inspection missions. Executing these missions, however, requires accurate localization and navigation. Although GPS-based navigation is well established, signal degradation and blockage caused by large-scale structures often cause GPS unreliable in inspection environments. This necessitates robust localization in GPS-denied settings, which remains a major challenge for large infrastructure. Existing approaches typically rely on loop-closure-based SLAM, requiring repeated observations of the same scene and still suffering from accumulated drift. Moreover, fully autonomous navigation in complex and dynamic inspection environments can pose safety risks when close-range inspection is required, limiting its practical applicability.

To address these challenges, this study proposes a model-based localization and assistive navigation framework that enables semi-autonomous execution of preplanned inspection missions. The localization module utilizes a pre-existing digital twin of the structure as a global reference, eliminating the need for loop closure and significantly reducing long-term drift. Instead of relying on costly LiDAR sensors, the proposed approach employs depth images acquired from low-cost depth cameras. To enhance robustness in partially-modelled environments, a semantic segmentation model filters out non-structural elements, ensuring that registration is performed only on structural components represented in the digital twin. Building upon this localization capability, an assistive navigation system is developed to provide real-time visual guidance to human pilots, enabling accurate trajectory tracking and pose control along preplanned inspection missions in GPS-denied environments, while leveraging human-in-the-loop control to mitigate unsafe maneuvers caused by localization uncertainty or dynamic surroundings.

By combining model-based localization with human-in-the-loop navigation, the proposed framework achieves a favorable balance between operational safety and automation, making it well suited for real-world infrastructure inspections. The framework facilitates reliable execution of optimized inspection missions while significantly reducing pilot workload and dependency on manual judgment. Furthermore, the modular design of the proposed system allows seamless integration with advanced inspection planning, perception, and autonomy modules, providing a scalable pathway toward fully autonomous visual inspection.

Speaker



Yuxiang Zhao

Mr. | University of Illinois Urbana-Champaign

ID 260: Dynamic Assessment & Reconnaissance Targeting: A Human-Centered AI Copilot for Targeted Post-Disaster Reconnaissance

2:35 PM – 2:55 PM

Author(s): Pedro Romero Santiago, Texas A&M University; Zihao "Scott" Li, Texas A&M University; Chenchen Kuai, Texas A&M University; Stephanie Paal, Texas A&M University

The Structural Extreme Events Reconnaissance (StEER) Network gathers, coordinates, standardizes and directs the mobilization of research teams with the ultimate goal of gathering current and perishable data following natural disasters worldwide. Since its foundation, StEER has reached this goal through a tiered operational workflow with a primary output of reconnaissance reports at varying stages. However, with the current workflow a significant bottleneck effect has been reached: while field deployment decisions must follow the urgency of the disaster, the supporting Preliminary Virtual Reconnaissance Reports (PVRs) average over 30 days to publish.

A misconception within this issue is that latency is driven by report writing speed. While recent advances in the implementation of Large Language Models (LLMs) have successfully automated event summaries, in order to assist the teams conducting the preparation of these reports (VAST teams), these tools largely function as news aggregators and summarizers, leaving a lack of deep technical tracing required to provide an sound engineering decision.

This study identifies the primary bottleneck not as writing latency, but rather the Information Retrieval Latency. This being the load placed on each member of the VAST team in order to sift through high-volume, actively increasing, unstructured data and news sources, in order to locate specific technical evidence capable of influencing their decision. To target this, we propose the Dynamic Assessment & Reconnaissance Targeting (D.A.R.T.) framework.

Unlike an approach attempting to replace the human expert, D.A.R.T functions as a human-centered guidance to optimize the search process. The framework proposed utilizes a Retrieval-Augmented Generation (RAG) architecture anchored in an existing and publicly available database of over 60 expert written historical StEER PVRs. This workflow proceeds in the following phases:

Contextual Strategy Injection: Upon a new event trigger, the system compares the observed disaster with historically analogous disasters through the implementation of vector embeddings. This leads to the generation of a dynamic "Technical Checklist" aimed at transforming the VAST team from passive researchers into active verifiers and developers.

Human-in-the-Loop Verification: VAST team members utilize these targeted directives to validate evidence, research into comparable areas, and ensure the prioritization of data which will have the most implications on a deployment decision. As the team continues to prepare the report, the "Technical Checklist" evolves in order to guide the team towards most specific constraints and targeted areas.

The Circuit Breaker: An automated severity monitor continuously analyzes incoming verified data in real time. If the damage observed exceeds historical deployment thresholds and destruction, the system triggers an immediate deployment recommendation. This decouples the operational decision from a final report publication, prioritizing the urgency of the disaster.

The shift described of utilizing AI from an automated writer to automated decision supports aims to fill the gap of reducing the time required to reach a decision from weeks to within an adequate and realistic timing ensuring the scarce engineering resources are deployed with greater utilization, precision, and speed.

Speaker



Pedro Romero Santiago

Mr. | Texas A&M University

ID 335: Asphalt Pavement Surface 3D Reconstruction and Texture-Based Distress Assessment through Depth-Supervised Neural Radiance Fields

2:55 PM – 3:15 PM

Author(s): You-Lin Chuang, National Yang Ming Chiao Tung University; Yu-Ting Huang, National Yang Ming Chiao Tung University; Wei-Sheng Lin, National Yang Ming Chiao Tung University

Title: Asphalt Pavement Surface 3D Reconstruction and Texture-Based Distress Assessment through Depth-Supervised Neural Radiance Fields

Pavement surface texture is a primary determinant of ride quality and overall road serviceability. Longitudinal roughness is commonly used to describe general pavement condition. However, localized surface distresses such as raveling and polishing play an important role in roadway safety and user comfort. Raveling refers to the progressive loss of aggregate from the asphalt pavement surface, while polishing involves the smoothing of aggregate micro-texture. Both are ride quality related distresses within the Pavement Condition Index (PCI). Despite their importance, accurate assessment of these defects typically relies on labor-intensive visual inspections or expensive high-resolution laser scanning systems. The high cost and operational complexity of these approaches limit inspection frequency, especially on city-level road networks. As a result, scalable and cost-effective alternatives are needed to resolve fine-grained surface texture.

To address this challenge, this study proposes an asphalt pavement surface reconstruction framework based on Depth-Supervised Neural Radiance Fields (DS-NeRF) using a low-cost RGB-D sensing suite. A ROS 2–based data acquisition system was developed, integrating an RGB-D camera, an inertial measurement unit (IMU), and an edge computing platform. The system records synchronized RGB-D imagery and camera intrinsics, while accurate camera pose estimation is obtained through a visual simultaneous localization and mapping (SLAM) algorithm. This sensing and processing pipeline enables dense data capture under realistic field conditions while maintaining low deployment cost.

Conventional NeRF models are difficult to apply to asphalt surfaces, as reflective binders and visually uniform textures hinder accurate reconstruction. To overcome these limitations, active stereo depth maps are incorporated as a physics-based geometric constraint within the DS-NeRF formulation. Depth supervision enforces physical scale, improves geometric consistency, and suppresses reconstruction artifacts such as ghost geometry. A physics-informed loss function further aligns radiance-based rendering with measured depth, resulting in cleaner and more reliable surface reconstructions.

The proposed framework resolves subtle geometric features associated with raveling-induced structural pitting and polishing-related micro-texture smoothing. Experimental results demonstrate millimeter-level geometric fidelity, enabling quantitative assessment of surface degradation from early aggregate exposure to advanced volumetric material loss. These findings highlight the potential of DS-NeRF–based digital twins as a practical and high-resolution solution for automated pavement monitoring that extends beyond coarse condition classification.

Keywords: Asphalt Pavement, Pavement Condition Index (PCI), Raveling, Polishing, NeRF, RGB-D Fusion, Infrastructure Monitoring.

Speaker



You Lin Chuang

graduate student | National Yang Ming Chiao Tung University

ID 782: Temporal Windowing for 3D Attention Analysis in Bridge Inspections Using Eye Tracking

3:15 PM – 3:35 PM

Author(s): Daniel Jimenez Gil, University of Illinois

Visual inspection is the primary method for bridge assessment, yet cognitive studies using eye tracking are often limited by the complexity of 3D environments. Existing research frequently imposes restrictive experimental controls, such as 2D simplifications or manual Area of Interest (AOI) definitions, which reduce ecological validity. This study proposes a novel approach that segments 3D inspection data into temporal windows to enable 2D gaze metrics and classifies behavior into three modes: global scanning, local inspection, and navigation. By transforming gaze data into a time-dependent signal, we extracted behavioral descriptors, including Markov transition probabilities and dwell-time distributions. We perform a user study using a Unity 3D bridge simulation with eight participants. Our results show that inspection mode timeseries and eye-movement patterns effectively predict inspection quality and correlate with spatial reasoning. These findings establish a foundation for research into task prediction, visual search behavior, and the role of expertise in infrastructure inspection.

Speaker



Daniel Jimenez Gil

Research Fellow | University of Illinois Urbana-Champaign

MS 039: Architected Materials

2:15 PM – 3:35 PM | Location: HUMN 125

Chair(s): Yunlan (Emma) Zhang; David Restrepo; Josephine Carstensen; Nilesh Mankame; Pablo Zavattieri

Moderators



Emma Zhang

Assistant Professor | University of Texas at Austin

ID 645: A Statistical Mechanics Approach to Understanding Fracture in Brittle Architected Materials: Disordered Bone-Inspired Architected Cementitious Materials

2:15 PM – 2:35 PM

Author(s): Shashank Gupta, Princeton University; Reza Moini, Princeton University

Statistical mechanics provides a powerful tool to capture and quantify order in arrangements of heterogeneous natural or engineered (topological, architected) materials and, therefore, provides a unique lens toward the computational design of materials and structures. However, these powerful methods to quantify a spectrum of order-to-disorder arrangements have rarely been used in the domains of architected materials. In this work, a statistical mechanics-based framework is introduced to rigorously quantify order and disorder in architected materials and to probe its relationship with fracture behavior. Classical statistical descriptors, namely the radial distribution function $g_2(r)$ and order parameters (Translational, T and orientational, Q), are proposed for the first time to quantitatively characterize disorder in architected material. These metrics enable representation of material arrangement along a continuous disorder spectrum bounded by two theoretical limits, an ideal random arrangement analogous to an ideal gas and a perfectly ordered face-centered cubic crystal. This framework replaces ambiguous periodicity classifications and misperceived disorder metrics, such as perturbation and Voronoi tessellation methods, and establishes a foundation for inverse design of engineered arrangements with prescribed levels of disorder.

The proposed disorder framework is applied to cortical bone-inspired tubular architected materials. Cortical bone is a remarkably tough biological material composed of tubular osteons embedded within an organic matrix and surrounded by weak interfaces known as cement lines. These cement lines act as preferential pathways for crack deflection, forcing cracks to propagate in-plane around osteons rather than straight through the material, thereby enhancing fracture toughness. Inspired by this natural toughening mechanism, tubular architected cementitious materials are designed with controlled disorder in tube size, shape, orientation, and spatial arrangement. The disorder-fracture relationship in these tubular systems is investigated using a combined computational and experimental approach. Crack propagation and crack-tube interactions are simulated using a phase-field fracture framework, implemented via a user element subroutine in the finite element platform Abaqus. This computational approach enables robust modeling of brittle fracture in the presence of engineered tubular defects and allows systematic exploration of a broad design space guided by the proposed statistical mechanics-based disorder parameters. Results reveal that the interplay of specific design parameters promotes a stepwise cracking mechanism, characterized by repeated crack arrest and reinitiation at tubular features. This stepwise fracture process leads to enhanced fracture resistance by preventing sudden, catastrophic failure.

Experimental fracture testing of the architected tubular cementitious materials also demonstrates a stepwise cracking mechanism that enables non-brittle fracture where tube size and ellipticity play key roles, further validating the computational simulations. Overall, this work establishes a quantitative disorder descriptor for architected materials and demonstrates its critical role in governing fracture behavior, offering a powerful pathway for the design of tough, damage-tolerant architected materials.

Speaker



Shashank Gupta

Postdoctoral Research Associate | Princeton University

ID 296: Numerical Modeling of Bio-inspired 3D Printed Concrete for Impact Resistance

2:35 PM – 2:55 PM

Author(s): Loukham Shyamsunder, Indian Institute of Technology Tirupati; Yu Wang, Purdue University; Pablo Zavattieri, Purdue University

Mantis shrimps are carnivorous crustaceans known for striking their prey with tremendous force using their dactyl clubs. Over thousands of years of evolution, these sea creatures have optimized the microstructures of their dactyl clubs to withstand repeated impact. The microstructure consists of multiple regions, among which the regions with Bouligand and the herringbone structures play a critical role in impact resistance. Previously, taking inspiration from these natural microstructures and enabled by the recent advancement in additive manufacturing techniques, fiber reinforced concrete structures with bio-inspired architectures had been 3D printed to create impact resistance structures. The bio-inspired 3D printed concrete structures with Bouligand and herringbone architectures were subjected to impact loading through laboratory experiments, and their performances were compared against conventional 3D printed concrete which consisted of straight filament patterns. For reference, their impact resistance was also compared against cast concrete structures. Experimental characterization showed that the architected concrete structures were superior to both conventionally 3D printed and cast concrete structures. Following the experimental study, this work aims to build numerical models to gain deeper insight into the underlying impact resistance mechanisms of these structures. Finite element models of these structures are developed and subjected to an impact energy of 56.7 Joules. The concrete filaments in the 3D printed and the cast structures are modeled using solid elements with pressure dependent plasticity-damage material model whereas the interfaces in the 3D printed concrete are modeled using cohesive zone elements and tiebreak contact definitions. The numerical results show that the architected 3D printed models are superior to the conventionally 3D printed and the cast concrete models, which agree with the experimental observations. Furthermore, qualitative assessment of the damage in the finite element models shows delocalization of damage in the architected 3D printed concrete models, in contrast to localized damage in the conventionally 3D printed and the cast concrete models. Notably, the architected concrete models do not exhibit complete fragmentation, in agreement with experimental findings.

Speaker



Loukham Shyamsunder

Assistant Professor | Indian Institute of Technology Tirupati

ID 265: Sub-Sized Fracture Testing Enabled by Electroplating: Experimental and Computational Feasibility Study

2:55 PM – 3:15 PM

Author(s): Benjamin Spencer, Idaho National Laboratory; Malachi Nelson, Idaho National Laboratory; Giang Huynh, Idaho National Laboratory; Yuxin Hu, University of California Berkeley; Muhammad Jahangir Khan Lodhi, Idaho National Laboratory; Fei Teng, Idaho National Laboratory; Peter Hosemann, University of California Berkeley

Fracture toughness is an important metric of a material's resistance to crack propagation. To measure this property, testing procedure standards dictate that a specimen must meet a minimum size condition to ensure that the material at the crack tip is adequately constrained to achieve plane strain conditions, and to ensure that the size of the plastic zone is small relative to the specimen. The minimum size required to meet those conditions can be difficult to achieve in situations when small amounts of material are available for testing. Testing materials irradiated in nuclear reactors is an important scenario for which there are severe constraints on the size of specimens available for testing due to the limits on space and time for irradiation in material testing reactors. Sub-sized fracture specimens are used in such cases, but they can be problematic because they may not meet the size criteria imposed by standards.

A potential alternative solution is to increase the size of a small specimen using electroplating to deposit a relatively thick layer of another material on a base specimen of the material to be tested. This process could be applied to a variety of specimens, but the focus here is on compact tension specimens, the size of which could be increased in either the in-plane direction or through-thickness direction using electroplating. To obtain useful results from such specimens, it is essential that the material near the crack tip still be in a stress state that closely matches that of a standard fracture specimen made of a single material. For this to be the case, it is important that the properties of the plated material are reasonably compatible with those of the base material, that the strength of the bond between the base material and plated material is sufficient to ensure stress transfer without bond failure, and that the processes used in electroplating have minimal impact on the base material.

An effort is currently underway to assess the feasibility of the electroplated fracture test concept. Techniques to plate nickel on base specimens of either steel or nickel-based alloys have been refined and have been demonstrated to be able to produce plating layers several millimeters thick. The mechanical properties of the plated layer and its interface with the base metal have been quantified through mesoscale tensile testing. Finite-element modeling of the plated specimens suggests that the properties of the plated material are adequate to provide the constraint needed for fracture tests. Fracture testing to assess the ability of a plated specimen to replicate the behavior of a baseline specimen is currently underway. This presentation will summarize the current progress of the effort to prove the viability of this concept.

Speaker



Benjamin Spencer

Computational Scientist | Idaho National Laboratory

ID 958: Optimization of an X-Shaped Elastomeric Architected Unit for Energy Absorption

3:15 PM – 3:35 PM

Author(s): Amin Joodaky, Michigan State University; Reza Najafi Zare, Michigan State University

"Architected elastomeric structures provide a geometry-driven alternative to stochastic polymeric foams for energy absorption in protective systems. This study presents the design, fabrication, and mechanical characterization of an X-shaped silicone rubber architected unit with a central neck, manufactured via cast molding using a 3D-printed PLA mold. Under quasi-static compression, the structure exhibits a three-stage force–displacement response consisting of an initial elastic regime, a pronounced buckling-dominated plateau, and a densification regime, closely resembling the constitutive behavior of polymer foams widely used in protective packaging.

A parametric investigation is conducted to optimize the unit geometry by varying the leg inclination angle and the leg thickness-to-width ratio. These geometric parameters govern the critical buckling load, plateau stress level, and specific energy absorption, as well as the extent of stable post-buckling deformation. Optimization objectives include maximizing energy absorption efficiency and extending the plateau regime while maintaining deformation repeatability relevant to packaging cushioning performance.

The results demonstrate that foam-like mechanical behavior suitable for packaging applications can be achieved through controlled geometric instability rather than stochastic porosity. The findings establish mechanics-based design guidelines for reusable, tunable architected cushioning elements and highlight the potential of elastomeric metamaterials as sustainable alternatives to conventional foam materials in shock-mitigation packaging systems."

Speaker



Amin Joodaky

Assistant Professor | Michigan State University

MS 025: AI and Machine Learning for Risk, Uncertainty, and Resilience Assessment of Structural and Infrastructure Systems

2:15 PM – 3:35 PM | Location: HUMN 1B50

Chair(s): Milad Roohi; Mohsen Zaker Esteghamati; Doeun Choe; John van de Lindt

Moderators



Milad Roohi

Assistant Professor | University of Nebraska-Lincoln

ID 223: Adaptive Algorithm for Efficient Urban Seismic Loss Assessment Considering Time-Varying Population Characteristics

2:15 PM – 2:35 PM

Author(s): Hyeonju Park, Ajou University; Taeyong Kim, Yonsei University

Seismic disasters inflict catastrophic casualties and socio-economic losses in densely populated urban areas. Ongoing urbanization increases structural density and fosters complex functional interdependencies and correlations among diverse structures, amplifying regional damage from seismic events and necessitating rapid and accurate loss assessment frameworks. However, two major limitations persist in existing approaches. First, surrogate-model-based frameworks have been widely developed to alleviate the prohibitive computational burden associated with performing nonlinear dynamic analyses on large-scale building stocks in time-sensitive regional assessments. These surrogate models are typically trained on specific building portfolios, which limits their generalizability and makes it difficult to accurately assess buildings that are not represented in the training dataset, such as special or atypical structures. Second, although regional seismic loss assessment needs to account for multiple components, including building-related losses, human casualties, contents damage, and business interruption, most existing studies rely on algorithms based on static geographical characteristics. Such approaches fail to capture time-varying disaster contexts, particularly the diurnal redistribution of population and socio-economic activities (i.e., the systematic shift of occupancy and activity centers from commercial, office, and educational facilities during the day to residential areas at night), which can significantly bias loss estimates and undermine assessment reliability. To address these limitations, this study proposes an adaptive regional seismic loss estimation framework that explicitly incorporates time-varying population characteristics. Seismic responses of buildings are initially estimated using a deep neural network-based Gaussian process surrogate model. To enhance prediction accuracy, a limited number of buildings are adaptively selected for high-fidelity nonlinear dynamic analysis. The selection strategy accounts for both prediction uncertainty and the potential contribution of buildings to human losses under diurnal population patterns. This ensures both evaluation flexibility and computational efficiency by optimally allocating a limited simulation budget according to the specific demands of a disaster scenario. The proposed framework is validated through a case study of a dense metropolitan area, demonstrating its potential as a robust decision-support tool for post-earthquake damage prediction and recovery planning.

Speaker



현주 (Hyeonju) 박 (Park)

M.S. | Ajou University

ID 253: Enhancing tornado damage prediction for Older URM Buildings through feature importance analysis

2:35 PM – 2:55 PM

Author(s): Yishuang Wang, Penn State; Rebecca Napolitano, Penn State

Communities rich in cultural heritage are increasingly prone to tornadoes, yet the structural resilience of Older Unreinforced Masonry (URM) buildings remains understudied. The state-of-the-art platform, IN-CORE (Interdependent Networked Community Resilience Modeling Environment), predicts the probability of each building reaching each damage state in a community level scale relying on Monte Carlo sampling within performance-based engineering frameworks. This method generates a probabilistic damage prediction for each building from a specific wind speed within the Enhanced Fujita (EF) scale range, rather than across a continuous wind spectrum. Consequently, this approach introduces stochasticity into model predictions, often leading to discrepancies between simulation results and observed damage and difficulties in measuring them.

To address these gaps, we propose a multi-stage framework to assess model accuracy and analyze the features contributing to the discrepancy between hindcasted and actual building damage observed in the 2020 Nashville Tornado and the 2021 Quad State Tornadoes. First, we address the stochastic nature of the IN-CORE model by grouping results into strata and adopting the Ranked Probability Skill Score (RPSS) to quantify the divergence. Second, we benchmark machine learning models and apply SHAP analysis to identify the collected building characteristics that impact the difference in both hazard-inclusive and hazard-neutral scenarios. Spatial cross-validation and spatial residual analysis are employed to validate the model's analytical findings. This framework enables the comparison between real-world observations and model predictions under stochastic settings, identifying which parameters are critical, overlooked, or require calibration to improve future damage assessments.

Speaker



Yishuang Wang

Pennsylvania State University

ID 325: Scalable Graph-Based Surrogate Modeling for Regional Storm Surge Hazard Estimation

2:55 PM – 3:15 PM

Author(s): Parisa Toofani Movaghar, University of Notre Dame; Alexandros Taflanidis, University of Notre Dame; Norberto Nadal-Caraballo, U.S. Army Corps of Engineers; Madison Yawn, U.S. Army Corps of Engineers; Luce Aucoin, U.S. Army Corps of Engineers; Kohl Morris, U.S. Army Corps of Engineers

Rapid urbanization in coastal regions, combined with growing climate-driven concerns about sea-level rise and extreme events, has made storm-surge hazard prediction a critical priority for community resilience and adaptation. Coastal infrastructure resilience depends on how well we can quantify storm-surge hazards, both the expected surge levels and the uncertainty that drives risk-relevant decisions. High-fidelity numerical hydrodynamic models (e.g., ADCIRC) can provide accurate surge estimation for individual storm events, but probabilistic hazard estimation requires ensembles with thousands of storms, making high-fidelity simulation prohibitively expensive. This motivates AI-enabled surrogate models that translate storm simulation databases into fast and reliable hazard predictions. Storm-surge surrogate models for this application are typically built using existing synthetic storm databases. These databases contain several hundred up to a thousand synthetic storms and provide peak surge values across extensive spatial domains, often exceeding one million nodal locations. The objective of surrogate is generally to approximate the peak surge response across all nodes for a new storm. In practice, this is difficult for several reasons: (i) the geo-spatial nodal grid is highly irregular and unstructured, (ii) surge response exhibits sharp spatial discontinuities driven by complex coastal features (e.g., bays, abrupt elevation transitions, channels, and flood-protection systems), and (iii) many nearshore locations remain dry during certain storms, leading to structured missing values in existing databases. When coupled with the massive number of nodes, these characteristics create substantial challenges in surrogate-model design, memory footprint, and generalization. To address these challenges, this study proposes a scalable graph-based surrogate for regional storm-surge hazard estimation over large coastal domains. The approach represents the coastal grid as a sparse graph in which nodes correspond to geospatial locations and edges encode inter-nodal dependencies. Rather than relying only on spatial proximity, the framework introduces response-based similarity: locations are connected when they exhibit consistent surge behavior across storms, serving as a proxy for hydraulic connectivity. Sparsity is enforced by retaining only the strongest dependencies per node, enabling memory-conscious training and inference at a regional scale. To address missing values in dry regions, this study specifically explores the incorporation of an elevation-informed constraint, since conventional remedies such as omitting missing values can discard important boundary information, while imputation can bias results and reduce robustness near sharp dry-wet transitions. Beyond these challenges, there are additional complexities associated with graph neural networks themselves that must be addressed. The graph surrogate requires nodal features, while storms are typically described by global parameters shared across the domain. We bridge this mismatch by learning storm-to-node mapping and enriching the resulting nodal inputs with location-specific wind field components. Overall, the proposed framework advances AI-enabled storm-surge surrogates that are scalable, interpretable through their graph-construction choices, and aligned with uncertainty-aware risk assessment workflows for resilient infrastructure planning and management.

Speaker



Parisa Toofani Movaghar

Ms. | University of Notre Dame

ID 464: Integrated Path Optimization for Wildfire Evacuation and Firefighting Access using Multi-Agent Reinforcement Learning

3:15 PM – 3:35 PM

Author(s): Taehoon Kang, Ajou University; Taeyong Kim, Yonsei University

As climate change increases the uncertainty surrounding wildfire spread, the need for real-time response technologies is becoming increasingly apparent. Effectively mitigating wildfire damage requires simultaneous coordination of resident evacuation and firefighting deployment. Existing approaches often treat evacuation and firefighting access as independent problems, making it difficult to address shared resource conflicts such as bottlenecks. Furthermore, many methods rely on static initial forecast data, failing to account for dynamic changes in the fire front caused by complex interactions among various factors such as wind speed, wind direction, and fuel moisture content. To address this research gap, this study proposes an integrated framework based on multi-agent reinforcement learning that uses the multi-agent proximity policy optimization (MAPPO) algorithm to generate optimal routing strategies for both residents and firefighters. This approach optimizes individual agents while simultaneously enhancing system-wide synergy. Agents receive real-time local fire risk information and network-wide wildfire spread trends every hour, allowing them to consider both local conditions and global spread patterns. The learning process is conducted using a two-tiered reward function tailored to the characteristics of each agent group (residents and firefighters). Resident agents are trained to minimize bottlenecks and safely reach shelters, while firefighter agents are optimized to quickly access the most active fire front. The framework proposed in this study enables collaborative strategies to resolve spatial conflicts and improve overall response efficiency by jointly training both agent groups in an integrated environment. Dynamic fire front data is utilized to ensure adaptability to rapidly changing situations, and a graphical user interface (GUI) is implemented to enhance practicality. Furthermore, deploying the developed algorithm through a GUI enhances applicability and usability. The model's pathfinding performance is verified using a numerical example of a wildfire in Andong, South Korea. This study provides foundational technologies for intelligent wildfire disaster management and supports real-time decision-making in the event of a large-scale wildfire.

Speaker



Taehoon Kang

M.S. | Yonsei University

MS 027: Bridging Numerical Modeling and Scientific Machine Learning for Next-Generation Computational Mechanics

2:15 PM – 3:35 PM | Location: HUMN 150

Chair(s): Somdatta Goswami; Souvik Chakraborty

Moderators



Somdatta Goswami

Assistant Professor | Johns Hopkins University

ID 133: Resolution-Agnostic Operator Learning for Transient Mechanics

2:15 PM – 2:35 PM

Author(s): Diab Abueidda, New York University Abu Dhabi; Mbebo Nonna, New York University Abu Dhabi; Panos Pantidis, New York University Abu Dhabi; Mostafa Mobasher, New York University Abu Dhabi

Learning solution operators for time-dependent PDEs from sparse, irregular observations remains difficult. Existing recurrent DeepONet variants inherit the discrete-time constraints of seq2seq RNNs, whereas neural-ODE surrogates generally cannot accommodate additional inputs once initialized. We propose NCDE-DeepONet, a continuous-time operator architecture that places a Neural Controlled Differential Equation (NCDE) in the branch network and enriches the trunk with explicit space-time coordinates. The NCDE compresses the full loading history into a latent state by solving a controlled ODE driven by a spline-interpolated input trajectory, yielding an input-resolution-independent encoding that is consistent across differing discretizations of the same observed signal. The trunk then probes this latent trajectory at arbitrary spatial points and times, producing an output-resolution-independent operator: solutions can be evaluated on previously unseen meshes and time grids without retraining or post hoc interpolation. Experiments on transient Poisson, elastodynamic, and thermoelastic benchmarks demonstrate strong robustness and accuracy, enabling near-instantaneous solution prediction. Overall, the results indicate that NCDE-DeepONet offers a principled and efficient basis for high-fidelity operator learning in transient mechanics.

Speaker



Diab Abueidda

Research Scientist | New York University Abu Dhabi

ID 288: The Integrated Finite Element Neural Network (IFENN) approach to phase-field fracture initiation and propagation

2:35 PM – 2:55 PM

Author(s): Panos Pantidis, New York University Abu Dhabi; Fouad Amin, New York University Abu Dhabi; Diab Abueidda, New York University Abu Dhabi; Mostafa Mobasher, New York University Abu Dhabi

In this work we expand the previously proposed Integrated Finite Element Neural Network (IFENN) to simulate the complete evolution of cracks within a phase-field formulation, encompassing both crack initiation and propagation. IFENN is a hybrid computational methodology that embeds pre-trained neural networks into a nonlinear finite element (FEM) solver to accelerate the solution of multi-physics problems. The mechanical equilibrium is resolved using conventional FEM, whereas the remaining physics-based equations are approximated by a pre-trained neural network (NN). The key feature of the framework is the iterative exchange of information between the two solvers, akin to a staggered scheme, which avoids blind full-field predictions and ensures seamless coupling between the two numerical methods.

Here we showcase how IFENN can be implemented to model the particularly challenging problem of phase-field crack evolution, involving both the initiation (pre-peak) and propagation (post-peak) stages. For the first stage the neural network of choice is a Deep Operator architecture with Kolmogorov Arnold Networks (KANs) for the branch and the trunk, while crack propagation is modelled with the aid of Convolution Neural Networks (CNNs). Both networks are trained exclusively on the physical relationship between the maximum strain energy density and the phase-field variable, utilizing very few training increments and avoiding expensive data generation. We note that KANs naturally accommodate unstructured data, whereas, during the propagation stage, this capability is achieved through a fast interpolation step that maps unstructured finite element data onto a structured grid suitable for CNN inference. The proposed framework is implemented across several benchmark problems, readily demonstrating the accuracy, computational speedup, and generalizability across unseen test cases.

Speaker



Panos Pantidis

Research Associate | New York University Abu Dhabi

ID 383: GAPS GAN Framework for Robust Extrapolation in Data Limited Computational Mechanics

2:55 PM – 3:15 PM

Author(s): Emiliano Garcia de la Cadena Gonzalez, Texas A&M University; Stephanie Paal, Texas A&M University

Data-driven models are increasingly used in order to predict how a structure will respond when physics-based simulations or extensive experiments are impractical. However, in many engineering situations, available data is often limited, resulting in large gaps across the parameter space and unreliable predictions when the model is used for extrapolation, especially in extreme conditions. This study addresses this challenge through a combined approach that involves analyzing gaps in the data and using generative modeling to address them.

A structured framework termed Gaps Across the Parameter Space (GAPS) was introduced in order to address this issue. This allowed machine learning models to be tested for robustness and generalization when limited data is available. The method works by gradually removing data from the target domain across the response variable, creating larger gaps while still keeping the connection between source and target data realistic. Using datasets of reinforced concrete columns and walls as examples of structural systems, the study tests baseline regression models and transfer learning techniques to see how they perform as these data gaps grow. The results demonstrate that traditional data driven models experience an abrupt decline in performance as the GAPS increase, while transfer learning models help in reducing this instability, although they still remain sensitive to extreme GAPS scenarios.

In order to overcome these limitations, this study introduces a data augmentation strategy based on Generative Adversarial Networks (GANs). The purpose of this is for synthetic data to be generated in regions with data gaps, which is then used to enhance transfer learning models, improving their stability and predictive performance for extreme extrapolative scenarios. The combined GAPS-GAN framework allows for a systematic evaluation of how synthetic data impacts model robustness as the data gaps increase, providing insight on the complex relationship between data scarcity, distributional shifts, and learning strategies.

This work treats extrapolation failure as a controlled stress test for computational models and introduces generative augmentation to address these challenges. By doing so, this study advances the development of machine learning techniques for predicting structural responses under extreme and unobserved conditions. The proposed framework offers a generalizable approach to improving the transferability and reliability of models for future computational mechanics applications, even with limited or incomplete data.

Speaker



Emiliano Garcia De La Cadena Gonzalez

Graduate student | Texas A&M University

ID 385: An Adaptive Hybrid Neural Operator–Implicit Solver Framework for Metamodeling of Nonlinear Stochastic Dynamic Systems

3:15 PM – 3:35 PM

Author(s): Haimiti Atila, University of Michigan; Somdatta Goswami, Johns Hopkins University; Seymour Spence, University of Michigan

Simulating high-dimensional, nonlinear dynamic structural systems subjected to extreme natural hazards is computationally demanding, particularly for uncertainty quantification and performance-based design. Recent advances in neural-network-based metamodeling have shown promise in reducing this cost; however, many existing approaches, including physics-informed machine learning frameworks, do not enforce physical constraints during inference, limiting their reliability for practical structural engineering applications.

This study proposes a novel hybrid framework that integrates neural operators—a class of models designed to learn mappings between infinite-dimensional function spaces—with the classical Newmark–beta implicit time-integration scheme. While implicit integration methods inherently satisfy governing physical constraints, their computational expense is dominated by repeated evaluations of restoring forces. To mitigate this bottleneck, the proposed framework leverages a neural operator to efficiently approximate restoring forces based on prior structural states, thereby accelerating the time-integration process.

To maintain physical consistency during inference, the structural response is periodically corrected by solving the governing equations using the full Newmark–beta scheme after an adaptively determined number of hybrid time steps. The proposed approach is validated on a steel moment-resisting frame subjected to stochastic seismic and wind excitations. Generalization capability is evaluated by training the metamodel on one hazard type and testing it on the other, a scenario in which conventional machine-learning-based metamodels often fail.

Results demonstrate that the proposed framework achieves substantially higher accuracy than conventional approaches, yielding a 15 to 85 times reduction in mean absolute error compared to LSTM-based models, while providing a computational speed-up of approximately 2 to 4 times relative to traditional implicit integration.

Speaker



Haimiti Atila

Mr. | University of Michigan

MS 036: Human-Centered AI and Data-Driven Systems for Infrastructure and Community Resilience

2:15 PM – 3:35 PM | Location: HUMN 1B90

Chair(s): Katherine Flanigan; Hadi Salehi

Moderatorss



Hadi Salehi

Assistant Professor | Louisiana Tech University



Katherine Flanigan

Assistant Professor | Carnegie Mellon University

ID 463: Between People and Space: Modeling the Ecologies of Hybrid Work for Human-Centered Sustainability

2:15 PM – 2:35 PM

Author(s): Giovanna Pilot, EPFL; Andrew Sonta, EPFL

Hybrid work is often portrayed as a greener and more flexible future of employment, yet its true sustainability—both environmental and human—remains uncertain. Organizations today navigate an increasingly complex landscape, balancing investments in office operations, energy efficiency, and environmental commitments with the equally pressing demands of employee performance and well-being. This complexity arises not only from the multitude of interacting factors shaping contemporary work ecosystems, but also from their rapid and often unpredictable evolution. The introduction of hybrid work has reshaped lifestyles, organizational practices, and space use in ways that resist linear explanation and frequently result in rebound effects or unintended consequences. Without a comprehensive understanding of the social, individual, and environmental implications of these dynamics, the long-term sustainability of hybrid work arrangements remains elusive.

The present work seeks to develop a cohesive work ecosystem that reconciles such complexity through a human-centric approach aligned with sustainability goals. The work conceptualizes the workplace as a coupled socio-technical system in which employee behavior, organizational policies, and the built environment co-evolve. Rather than treating human behavior as an exogenous input, the proposed framework explicitly integrates employees' preferences, well-being, and perceived productivity into the analysis of space use and energy performance.

At the individual level, employee hybrid working preferences are elicited through a dedicated survey and modeled using discrete choice and latent-variable techniques grounded in utility theory. Decision models capture how workers value different attributes of hybrid work—such as flexibility, office presence, commuting conditions, and workspace characteristics—and how psychological constructs, including autonomy, relatedness, and job satisfaction, shape perceived well-being and productivity outcomes. By combining stated and revealed preference data, the behavioral models provide a coherent representation of heterogeneous employee responses to alternative hybrid work policies.

At the building level, behavioral outputs are linked to simulations of office space utilization and energy consumption under different hybrid work scenarios. Changes in occupancy patterns induced by policy choices are translated into energy demand profiles and spatial management strategies, allowing the environmental consequences of hybrid work arrangements to be quantified alongside human outcomes. These behavioral and physical dimensions are lastly integrated within a multi-objective optimization framework that jointly evaluates employee well-being, perceived productivity, space efficiency, and energy use.

The expected outcome of this research is a comprehensive framework that elucidates the trade-offs and synergies shaping sustainable hybrid work. By bridging individual, organizational, and environmental domains, the framework provides an evidence-based decision-support tool for organizations seeking to design hybrid work policies that support human well-being while reducing resource use. Indeed, more broadly, the work contributes to human-centered infrastructure research by demonstrating how behavioral modeling and engineering-based simulations can be combined to assess and manage socio-technical systems under conditions of structural change.

In the talk, we will present preliminary results from employee survey and the resulting behavioral models, providing insights into how individuals value key attributes of hybrid work policies and how these preferences translate into patterns of presence and space use. We will demonstrate how these behaviorally grounded models can be linked to simulations of building space utilization, occupancy, and energy demand to assess the human and environmental outcomes of alternative work policies. These insights form the core component of the broader multi-objective optimization framework intended to support more informed decision-making to contribute to governance approaches capable of aligning human well-being, operational performance, and environmental responsibility.

Speaker



Giovanna Pilot

PhD Student | EPFL - Swiss Federal Technology Institute of Lausanne

ID 613: Constructing Sociometric Networks Through LLM-Enabled Human Dialogue

2:35 PM – 2:55 PM

Author(s): Cheyu Lin, Carnegie Mellon University; Katherine Flanigan, Carnegie Mellon University

Social capital—the networks, norms of reciprocity, and interpersonal trust that facilitate cooperation—is a community asset enabling collective action, information flow, and resource mobilization. Research demonstrates that social capital strengthens infrastructure resilience: communities with stronger social capital spread information and coordinate resources more effectively to recover from infrastructure failures during and after disruptions. Given this tight connection between social capital and infrastructure resilience, measuring and analyzing a community's social capital is paramount. While existing studies have identified correlational relationships between social network characteristics and social capital, quantitative measures are still needed to establish functional relationships that enable strategic optimization. Sociometric networks offer a promising approach. Unlike conventional binary networks that capture only the existence of relationships, sociometric networks provide finer insights into relationship quality and strength—offering a vehicle to measure social relations within a community more precisely. However, sociometric networks are conventionally constructed via surveys, which are temporally discontinuous, costly, and laborious. In this work, we present a framework for constructing sociometric networks from human dialogue text, enabling real-time and economical measurement. Moreover, this framework is scalable and adaptable: the data are generated through large language models, allowing configuration for communities of different sizes and contexts.

Speaker



Cheyu Lin

Carnegie Mellon University

ID 619: Street View Images as a Multi-Application Data Source for Urban Digital Twins: Data Collection and Bias Correction

2:55 PM – 3:15 PM

Author(s): Kieran Elrod, Carnegie Mellon University; Katherine Flanigan, Carnegie Mellon University; Mario Berges, Carnegie Mellon University

Digital twins at the scale of cities have been frequently proposed but rarely executed outside of specific domains such as transportation, energy, and water systems. What makes these systems feasible to twin has nothing to do with their specific domain and has everything to do with data availability: in each of these cases, data is passively generated through operation via mobility traces—used to bill for and transfer cellular data—or metered usage of energy and water. Other urban systems—such as structural or social systems—could be twinned at the scale and fidelity of these systems if data was widely available.

Street view images (SVI) have been identified as a cheap, scalable data source with diverse urban applications from assessing facades and pavement quality to measuring social interactions. These images are currently available at low cost in the tens of millions across thousands of cities. In principle, the rich data present in these images could be used for any number of applications—such as structural or social systems. However, they have yet to be applied to these contexts because of widespread spatial and temporal biases in where street view images are taken: images are taken at convenient seasons, times, and locations rather than as an unbiased sample of the city.

Prior work has identified this bias in specific application areas: we take a pragmatic approach and assess how many new images would be needed to correct for the biases that exist. We develop an application agnostic bias framework for street view images and propose a spatiotemporal bias measure based on graph earthmover's distance. To study how this bias could be corrected, we assess how many new images would be needed to correct spatiotemporal bias across 6 US cities and where they would need to be collected. Finally, we explore the possibility of collecting these images using municipal vehicles.

Speaker



Kieran Elrod

PhD Candidate | Carnegie Mellon University

MS 066: Evaluating the Credibility of Computational Models and Digital Twins

2:15 PM – 3:35 PM | Location: CLUB 4-5

Chair(s): Patrick Brewick; Pranav Karve; Kyle Neal; Sakaran Mahadevan

Moderatorss



Patrick Brewick

Assistant Professor | University of Notre Dame



Pranav Karve

Assistant Professor | Vanderbilt University

ID 135: Considering Credibility and Confidence for Complex Engineering Models and Digital Twins

2:15 PM – 2:35 PM

Author(s): Patrick Brewick, University of Notre Dame; Ruijia Wang, University of Notre Dame; Jen Pazour, Rensselaer Polytechnic Institute

The scientific community has placed tremendous emphasis on harnessing the growing availability and capacity of computational tools to develop and create increasingly complex models of engineering systems. This complexity has enabled more detailed and realistic representations of engineering systems; however, even considering their high levels of detail and fidelity, these models are, by definition, merely representations of physical and mechanical systems. These advancements have also directly contributed to the emergence of digital twins, i.e. virtual representations of a given system or structure that are meant to mirror all relevant aspects and features. However, these digital twins are the culminations of dozens, if not hundreds or thousands, of design decisions and assumptions, rendering them imperfect representations of the real system. While there have been notable advancements in verification and validation techniques that quantify the degree to which a model can predict or replicate real-world observations, the complexity of modern digital twins as well as the scarcity of test data make it difficult, if not impossible, to fully evaluate all aspects of these complex models. Thus, even if the digital twin can be validated under certain configurations or with respect to some of its outputs, a larger question remains: How confident are we in this model's overall representative ability?

Answering this question requires an acknowledgment of both a model's technical and social dimensions. Humans play a significant role in creating and developing models like digital twins due to the numerous design decisions and assumptions made along the way. In this work, we suggest a more comprehensive framework is needed to address the multi-faceted problem of model confidence and account for human expertise. While acknowledging the importance of verification and validation approaches, this talk explores how the ideas of model credibility and model confidence can contribute to more holistic evaluations of model capabilities. For instance, while model credibility has been addressed in fields such as ecology and environmental modeling, this work suggests how paradigms from these fields can be transformed for application to complex engineering models. This work also discusses how concepts of model credibility and model confidence can be fused to more comprehensively address the impact of model assumptions, simplicity and consistency. Importantly, assessment of these attributes is dependent upon the knowledge and judgment of experts, which must be elicited through surveys and other elicitation protocols. Therefore, a series of suggestions are presented for synthesizing elicited knowledge into a more unified, quantitative measure of model confidence.

Speaker



Patrick Brewick

Assistant Professor | University of Notre Dame

ID 1024: Quantitative Approach for Model Credibility Assessment

2:35 PM – 2:55 PM

Author(s): Sankaran Mahadevan, Vanderbilt University, Nashville, TN; Oliver Stover, Charles River Associates, Boston, MA; Kyle Neal, Sandia National Laboratories, Albuquerque, NM; Joshua Mullins, Sandia National Laboratories, Albuquerque, NM

A conceptual framework for quantitatively assessing the credibility and risk of computational models is presented. The framework provides a systematic approach for aggregating information from a variety of model assessment activities to provide the decision-maker with quantitative information relating to model credibility.

The credibility of a computer simulation model represents the degree to which the decision-maker believes that utilizing the model prediction is acceptable for its intended application, based on the collected evidence. The proposed model credibility measure makes use of six assessment activities considered in the Predictive Capability Maturity Model (PCMM) developed at Sandia National Laboratories. Based on the maturity, strength and relevance of evidence provided by the six PCMM elements, Dempster-Shafer theory (DST) is employed to combine the assessment scores and provide a three-dimensional metric of model credibility: a $[0,1]$ measure of the degree of evidentiary support for the model's acceptability for its intended use, a $[0,1]$ measure of the degree of evidentiary support against the model's acceptability for its intended use, and a $[0,1]$ measure of the uncertainty about a model's acceptability due to lack of mature and/or relevant evidence.

The proposed methodology is demonstrated for the credibility assessment of a structural dynamics model for a challenge problem developed at Sandia National Laboratories.

Sandia National Laboratories is managed and operated by NTESS under DOE NNSA contract DE-NA0003525"

Speaker



Sankaran Mahadevan

Professor | Vanderbilt University

ID 563: Model risk quantification using evidence assessment

2:55 PM – 3:15 PM

Author(s): Pranav Karve, Vanderbilt University; Sankaran Mahadevan, Vanderbilt University; Kyle Neal, Sandia National Laboratories; Joshua Mullins, Sandia National Laboratories

Over the last few decades, tremendous advancements have been made in modeling and simulation (M&S) methods. Newly developed, high-fidelity M&S methods allow sophisticated information fusion, uncertainty management, and decision-making under uncertainty. However, quantification of the risk of making a wrong decision using the newly developed model is a difficult task. To address this knowledge gap, a novel model risk quantification framework is developed. Model risk is defined as the probability of making a wrong decision if the model is used for a particular use case. A methodology to evaluate the correctness of a decision made using a newly developed computational model is first developed. Note that the correctness of decisions made using a model is typically not considered in verification, validation, and uncertainty quantification (VVUQ) methods, which focus on model outputs.

The proposed model risk quantification method builds on credibility assessment that quantifies the belief or uncertainty regarding the new model's suitability for the application (decision-making problem) of interest. The proposed, rational decision evaluator thus uses two sources of information: a) credibility assessment results for the newly developed model, and b) the existing (alternate) decision model. A previously developed, three-dimensional model credibility measure is used to compute the probability of model success or failure. The three-dimensional credibility score measures the degree of evidentiary support for the model's acceptability for its intended use, against the model's acceptability for its intended use, and uncertainty about a model's acceptability due to lack of mature and/or relevant evidence. The credibility measure makes use of six assessment activities considered in the Predictive Capability Maturity Model (PCMM) developed at Sandia National Laboratories [1] and combines the evidence using Dempster-Shafer theory (DST). The quantitative model credibility information and the transferable belief model developed by Smets and Kennes [2] are used to compute betting probabilities related to model's success or failure. The betting probabilities are used as weights in Bayesian model averaging to construct a credibility-informed model by considering both the proposed model and the alternate decision model. Three cases are then developed based on the quantified model credibility: a) the model should not be used for making a decision, b) the model could be used and the alternate decision model is used to evaluate the correctness of the decision, and c) the model could be used and the credibility-informed model is to be used to evaluate the correctness of the decision. Novel credibility-risk maps are developed, which help visualize model risk under different levels of model credibility. This analysis also considers the decision context (failure threshold and acceptable failure probability), which is typically not considered during model credibility assessment.

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Speaker



Pranav Karve

Assistant Professor | Vanderbilt University

ID 333: Quantitative Assessment of Model Credibility Across the Project Lifecycle

3:15 PM – 3:35 PM

Author(s): Kyle Neal, Sandia National Laboratories; Pranav Karve, Vanderbilt University; Sankaran Mahadevan, Vanderbilt University; Alden Pack, Sandia National Laboratories; Aaron Krueger, Sandia National Laboratories; Josh Mullins, Sandia National Laboratories

Ensuring the credibility of computational models across a project's lifecycle is vital for robust decision-making in digital engineering. Traditional verification, validation, and uncertainty quantification (VVUQ) efforts often occur as one-off assessments, overlooking the evolving consequences and fidelity requirements from early conceptual design to final qualification. Early stages may tolerate coarser models and limited validation since decisions carry lower stakes; in contrast, detailed design and qualification demand demonstrably high model credibility to prevent late-stage surprises, costly rework, or system failures. We introduce a framework for tracking model credibility evolution throughout the project lifecycle and guiding targeted VVUQ planning to achieve predefined credibility objectives at each phase.

Our method extends the Predictive Capability Maturity Model (PCMM) by integrating three evidence dimensions—maturity, strength, and relevance—into its six core elements. We quantify and aggregate these dimensions to derive a composite credibility metric. By mapping this metric onto “betting” probabilities, we capture a decision-maker's confidence in the computational model relative to alternative sources, such as expert judgment, empirical interpolation, or bounding analyses. This credibility-informed indicator serves as a decision-support tool for allocating VVUQ resources and dynamically adjusting modeling fidelity as project needs evolve.

To translate credibility objectives into actionable VVUQ plans, we formulate a resource-allocation problem under budget constraints. Our approach selects and scales specific VVUQ activities—mesh refinement studies, targeted validation experiments, and uncertainty-quantification analyses—to meet stage-specific credibility targets while minimizing total effort. The resulting portfolios strike an optimal balance between evidence generation and cost efficiency.

We apply our lifecycle-driven framework to an electromagnetic shielding-effectiveness case study using a canonical box-with-slot geometry relevant to aerospace structures. The example demonstrates how systematic tracking of credibility metrics and optimized VVUQ portfolios enables engineering teams to mature model confidence in sync with decision thresholds. This methodology offers a quantitative, holistic means to enhance the reliability and trustworthiness of computational models and digital twins in complex engineering applications.

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Speaker



Kyle Neal

R&D Engineer | Sandia National Laboratories

MS 059: Retrofitting, Inspection, and Repair for Resilient Infrastructure Systems

2:15 PM – 3:35 PM | Location: CASE E230

Chair(s): Emad Hassan; Hussam Mahmoud; Mohamed ElGawady; Genda Chen

Moderators



Emad Hassan

Assistant Professor | Missouri University of Science and Technology

ID 905: Novel and Sustainable Strengthening Solution for Prestressed Bridge Girders

2:15 PM – 2:35 PM

Author(s): Mohammad Bani Hani, Kansas State University; Hayder Rasheed, Kansas State University

This study investigates the behavior of prestressed concrete bridge girders when strengthened with a novel lightweight, sustainable hybrid system. The system combines a short Aluminum Alloy plate sandwiched in-between two sheets of a sustainable and highly deformable material namely Polyethylene Terephthalate (PET). The short Aluminum Alloy (AA) plate is strategically placed around the critical section to attract all the metal plasticity allowing for a ductile performance. Since the plate is short, covering the constant moment region only, two thick Carbon Fiber Reinforced Polymer (CFRP) sheets overlap with the AA plate ends to further develop it into the shear span. Two PET U-wrap anchors are further applied to clamp and confine the overlapping distance between the constant moment region and the shear span. Four prestressed T-beams were tested, including a control specimen, a strengthened control specimen with PET sheets only, and two strengthened specimens using different hybrid strengthening configurations. The results indicate that the new strengthening system was superior to conventional strengthening methods in terms of deformability and energy dissipation. The PET sheets accomplished very large strain levels without encountering any premature debonding failure modes.

Speaker



Mohammad Bani Hani

PhD Candidate | Kansas State University

ID 588: A decision-support framework for selecting optimal water erosion control measures on roadside slopes

2:35 PM – 2:55 PM

Author(s): Eduardo Arancibia-Ruiz, Pontificia Universidad Católica de Chile & CIGIDEN R+; Alondra Chamorro Giné, Pontificia Universidad Católica de Chile & CIGIDEN R+; Esteban Sáez, Pontificia Universidad Católica de Chile & CIGIDEN R+; Manuel Contreras-Jara, Pontificia Universidad Católica de Chile & CIGIDEN R+; Tomás Echaveguren, Universidad de Concepción & CIGIDEN R+

Roadside slopes are highly vulnerable to hydrometeorological events, which trigger erosion processes, accelerating failure and landslides, resulting in road disruptions, potential accidents, and high direct and indirect economic costs.

There are various methods to reduce erosion processes on cut-slopes, among which erosion control meshes and blankets (ECM) stand out for their ease of implementation and low cost compared to other alternatives. However, despite their widespread use, many of the measures implemented are not biodegradable and have performed poorly after implementation.

Currently, there is no methodology available to select erosion-control measures that evaluate the most effective alternative, considering the physical-mechanical, chemical, economic, and environmental properties, to make the correct selection of the erosion control method to be implemented. Quantifying the performance of ECMs is essential prior to the installation of a control measure, favoring the reduction of erosive processes on cut slopes, improving resilience, and obtaining socio-economic and environmental benefits.

The research carried out aims to develop an analytical-empirical evaluation methodology to assess the effectiveness of ECMs on road slopes, validated at the laboratory scale. This analytical-empirical methodology assess the physical-mechanical, chemical, economic, and environmental performance of ECMs to evaluate their performance, considering commercially available solutions (natural and artificial measures), and using prototypes that incorporate sheep wool and fiber erosion control blankets.

The tests carried out consider 100-year return periods rainfall obtained from IDF (Intensity-Duration-Frequency) curves for the southern regions of Chile, which corresponds to an approximate value of 22 mm/h. The results show a reduction of more than 80% in surface runoff, a reduction of up to 86% in soil loss, and a correlation between the physical properties of the MCE and the characteristics of the soil in which it is implemented. The natural measures showed better performance than the artificial alternative, with high immediate effectiveness in reducing erosion processes and positive effects already known for the revegetation process on cut slopes.

Speaker



Manuel Contreras Jara

PhD Student, Civil Engineer | Pontificia Universidad Católica de Chile

ID 592: Network-Based Assessment of First Responder Functionality Under Seismic Hazards

2:55 PM – 3:15 PM

Author(s): Emad Hassan, Missouri University of Science and Technology

First responders are essential to reducing losses and ensuring community safety during and after disasters such as earthquakes. Their effectiveness, however, can be severely constrained when critical infrastructure and lifeline networks are disrupted. This study examines the resilience of first responders through the lens of network connectivity, using Missouri as a representative case study of a region exposed to significant seismic risk. The analysis employs a network-based framework that integrates probabilistic damage and recovery analyses for transportation and utility systems with spatial accessibility measures relevant to emergency operations. This approach allows the evaluation of how infrastructure damage affects first responders' mobility, access to critical facilities, and overall ability to sustain emergency services following seismic events. The results suggest that seismic damage to bridges, roads, and utilities can create substantial barriers to rapid response, with cascading effects that delay rescue operations and extend community recovery times. The results also highlight the importance of prioritizing resilience investments in transportation corridors and emergency facilities to ensure that first responders remain operational when communities need them most. This research contributes to the broader understanding of disaster resilience by advancing methods to evaluate first responder functionality under infrastructure disruption. The framework provides decision-makers with insights into how targeted mitigation strategies can strengthen emergency preparedness and improve resilience to seismic hazards.

Speaker



Emad Hassan

Assistant Professor | Missouri University of Science and Technology

ID 700: Damage Assessment and Recovery Estimation of Buildings and Electric Power Networks Following the March 2025 Rolla Tornado

3:15 PM – 3:35 PM

Author(s): Emad Hassan, Missouri University of Science and Technology; Ibrahim Gomaa, Missouri University of Science and Technology

The March 2025 tornado that struck Rolla, Missouri, caused widespread residential power outages and damage to the electric distribution network. This study presents a post-event assessment of power network damage and recovery using a network-based modeling framework. The electric power system is represented as a spatial network of power poles and distribution lines serving residential buildings, allowing evaluation of component vulnerability and outage propagation under tornado impacts. Network performance metrics are used to estimate residential power outage exposure based on network topology and component damage states. Observed damage and recovery are validated using outage and restoration records from Rolla Municipal Utilities, enabling comparison of modeled outage extents and recovery timelines with empirical utility data. Recovery trajectories are estimated by incorporating restoration sequencing and network redundancy into the model. Results demonstrate that network structure and pole vulnerability strongly influence both the spatial distribution of outages and recovery duration. The proposed approach provides a practical framework for post-tornado assessment and resilience evaluation of electric power networks.

Speaker



Emad Hassan

Assistant Professor | Missouri University of Science and Technology

MS 052: Stability of structures: Advances across time and scales

2:15 PM – 3:35 PM | Location: CASE E240

Chair(s): Noël Challamel; Hayder Rasheed; C.W. Lim; Stylianos Yiatros; Hyeyoung Koh

Moderators



Noël Challamel

Professeur | UNIVERSITE BRETAGNE SUD



Hayder Rasheed

Professor | Kansas State University

ID 154: Exact Buckling Solutions of Anisotropic Laminated Columns with Classical Boundary Conditions under Axial Compression

2:15 PM – 2:35 PM

Author(s): Hayder Rasheed, Kansas State University; Ahmad Ghabban, AEDA LLC

The exact buckling solutions of a generally anisotropic laminated composite thin column, with various classical boundary conditions, are developed. The effective axial, coupling and flexural stiffness coefficients of the anisotropic layup is extracted from the generalized constitutive relationship by statically condensing the 6x6 laminated composite stiffness matrix. The governing differential equations of anisotropic column buckling are further statically condensed to yield an effective stiffness coefficient in terms of the effective axial, coupling and flexural stiffness coefficients of the anisotropic layup that are extracted above. This makes the exact buckling load for the generally anisotropic layup a function of the three effective stiffness coefficients. The analytical results are verified against finite element Eigenvalue analysis and an approximate Rayleigh-Ritz solution of anisotropic columns for a wide range of geometric, material and support boundary conditions. The correspondence of the exact analytical, approximate Rayleigh-Ritz and numerical findings is discussed for all the examined cases.

Speaker



Hayder Rasheed

Professor | Kansas State University

ID 228: Geometrically exact strain-gradient Reissner elastica – Asymptotic, FDM and FEM analyses

2:35 PM – 2:55 PM

Author(s): Noël Challamel, Univ. Bretagne Sud, IRDL, France; Philippe Le Grogneq, ENSTA | Institut Polytechnique de Paris (Campus de Brest) - IRDL

This study is devoted to the theoretical and numerical buckling and post-buckling analyses of a strain-gradient shear-deformable elastic column under a compressive force, in a geometrically exact framework. This problem can be referred to as a strain-gradient Reissner elastica problem. The strain-gradient contributions independently concern the axial, shear and bending parts of the constitutive law. Applications of such a study can be found in the field of size dependent structural mechanics, where internal lengths can be introduced for realistic stiffening scale effects. Another application is the modelling of higher-order shear-deformable columns, such as the Bickford-Reddy's column or the Shi-Voyiadjis' column, which both can be classified as shear-deformable strain-gradient Timoshenko columns. Such a theoretical beam analysis includes the higher-order shear elastica problem. This generalizes Reissner's geometrically exact beam analysis (Reissner, 1972), which is able to take into account, in a rigorous and variational framework, the effects of bending, shear and extensibility in the buckling and post-buckling of simple elastic columns (see also Kocsis and Challamel, 2018, for the foundation of Reissner's beam theory based on discrete structural mechanics arguments). The governing equations of the strain-gradient Reissner elastica are introduced from the principle of virtual work, extended to gradient media (see Mindlin, 1964 or Germain, 1973), here restricted to a 1D non-linear problem. A single non-linear second-order differential equation for the rotation variable can be derived from Reissner's equations in presence of an axial compressive load. Exact solutions of the local Reissner elastica non-linear differential equations can be derived using complete elliptic integrals of the first kind (see for instance Humer, 2013). Conversely, the strain-gradient Reissner elastica problem necessitates the use of numerical methods. The Finite Difference Method (FDM), Finite Element Method (FEM) and a continuous asymptotic post-buckling analysis (as developed by Koiter, 1963 – see also Koiter, 2009) are applied here to compute the bifurcation point and post-bifurcation equilibrium branch. The corresponding solutions are compared to each other, for validation purposes. The stiffening phenomenon induced by the length scale gradient terms is confirmed for both the buckling and post-buckling behaviours. The convergence of the FDM from below, and the one of the FEM from above, are also confirmed in the non-linear range of the strain-gradient Reissner elastica.

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Speaker



Noël Challamel

Professeur | UNIVERSITE BRETAGNE SUD

ID 830: Harnessing Topological Phases and Structural Instabilities for Polarization-Controlled Elastic Wave Manipulation in a Hexagonal Metamaterial

2:55 PM – 3:15 PM

Author(s): Guifeng Wang, City University of Hong Kong; C.W. Lim, Zhejiang University

This study introduces a hexagonal truss-like metamaterial with internal resonators that enables polarization-dependent elastic wave manipulation through strategically designed structural instabilities and topological phase transitions. At low frequencies, local resonance induces subwavelength bandgaps capable of selectively filtering in-plane (IP) or out-of-plane (OP) vibrations. In higher frequency regimes, independent control over IP and OP topological bandgaps is achieved by exploiting accidental Dirac cones, leading to distinct valley Chern numbers and separate topological phases. By combining unitcells with distinct topological invariants, polarization-dependent topologically protected interface modes are established, which support robust and selective waveguiding exclusively for IP, OP, or both polarizations. A 3D-printed prototype is experimentally tested, confirming efficient polarization-based wave separation and routing even at structural intersections. The proposed system demonstrates how tailored instabilities and topological properties can be harnessed to design advanced elastic devices such as reconfigurable wave filters, multiplexers, and information-encoding platforms, offering new pathways for wave control in nonlinear and non-classical structural materials. This work bridges structural mechanics, wave physics, and structure design, highlighting the potential of instability-driven configurations in emerging metamaterial applications.

Speaker



C.W. Lim

Professor | Zhejiang University

ID 1042: Mode-Consistent Bifurcation Loads in the Vibration Correlation Technique for Improved Buckling Prediction of Composite Cylindrical Shells

3:15 PM – 3:35 PM

Author(s): Adrian Gliszczynski, Lodz University of Technology

The Vibration Correlation Technique (VCT) has emerged as a promising experimental approach for predicting the buckling loads of thin-walled composite shells based on measured vibration frequencies in the prebuckling range. In the classical formulation of VCT, the prediction relies on the reference critical load obtained from linear eigenvalue analysis, which is assumed to represent the global bifurcation point of the structure. However, the reference buckling mode may not correspond to the vibration mode used in the VCT procedure, which can introduce inconsistencies in the prediction process. This study proposes a modified VCT formulation in which the conventional critical buckling load is replaced by a mode-consistent analytical bifurcation load, corresponding to the buckling mode that is identical to the considered vibration mode. In this approach, the analytical bifurcation load is derived directly from shell stability theory and used as the reference load in the characteristic chart correlation procedure. This modification ensures physical consistency between the vibration mode used for frequency tracking and the associated buckling mechanism. The proposed methodology was investigated using a dataset of ten unstiffened CFRP cylindrical shells subjected to axial compression. High-fidelity finite element models were validated against experimental compression tests and used to extract vibration frequencies under increasing load. Predictions were performed using the Arbelo characteristic chart. The results demonstrate that replacing the classical critical load with the mode-consistent bifurcation load can further improve the robustness and conservativeness of the predictions. The findings indicate that the proposed mode-consistent bifurcation load provides a physically justified refinement of the VCT framework and represents a promising step toward more reliable buckling load prediction for composite shell structures.

This research was supported by the National Science Centre, Poland, under grant agreement no. UMO-2024/53/B/ST8/01594

Speaker



Adrian Gliszczynski

PhD | Lodz University of Technology

MS 060: Advancing a Functionality-Based Design Paradigm Grounded in Mechanics, System Modeling, and Decision Theory

2:15 PM – 3:35 PM | Location: KTCH 1B87

Chair(s): Lisa Wang; Milad Roohi; Emad Hassan

Moderators



Lisa Wang

Profes | Old Dominion University

ID 506: Power Distribution Restoration with Data Center Anchors via Graph-Based Reinforcement Learning for Enhanced Grid Resilience

2:15 PM – 2:35 PM

Author(s): Kamiar Khayambashi, University of Virginia; Negin Alemazkoo, University of Virginia

Rapid growth in hyperscale data centers driven by Artificial Intelligence is reshaping electric load patterns and increasing the consequences of widespread power outages under more frequent extreme weather. Although recent literature highlights that data centers possess substantial behind-the-meter flexibility through Uninterruptible Power Supplies (UPS), battery storage, and controllable computing and cooling operations, restoration practice still treats these facilities primarily as large, self-protecting loads. More importantly, the idea that data centers could serve as “restoration anchors” for grid recovery has been suggested, yet it has not been systematically tested or quantified within restoration-oriented decision frameworks. This work addresses that gap by evaluating when and how selected data centers can support post-disaster recovery while preserving their own operational requirements. We formulate a resilience-focused restoration problem that coordinates distribution network reconfiguration and prioritized load restoration with the availability of data center support under uncertain damage and repair conditions. To enable scalable decision-making over evolving grid states, we develop a graph neural network–based reinforcement learning policy that learns restoration actions from structured network representations and balances community recovery objectives against data center survivability constraints. Using hurricane-driven outage cases on benchmark distribution test systems, we quantify the resilience value of data center anchoring relative to conventional restoration and self-preservation-only operation using metrics such as Value of Lost Load (VOLL)-weighted unserved energy and time-to-restore critical loads. Findings provide evidence-based guidance on how digital infrastructure can be integrated into infrastructure management and utility restoration planning as an active resilience resource rather than a passive source of grid stress.

Speaker



Kamiar Khayambashi

Ph.D. Candidate | University of Virginia

ID 644: A Data-Driven Building Demolition, Reconstruction, and Vacancy Methodology Considering Geospatial Social Vulnerability

2:35 PM – 2:55 PM

Author(s): Sai Kiran Simhadri, Old Dominion University; Wanting (Lisa) Wang, Old Dominion University; John W. van de Lindt, Colorado State University; Blythe Johnston, Argonne National Laboratory; P. Shane Crawford, University of Alabama

Community post-disaster recovery is a significant yet underexplored research frontier. While existing studies have developed numerical models (e.g., probabilistic, agent-based) to simulate building repair trajectories, the critical pathway of building demolition, reconstruction, and long-term vacancy—and its driving factors, particularly geospatial social vulnerability—remains poorly quantified. Current models, such as HAZUS, often oversimplify demolition decisions or lack empirical validation. This study addresses this gap by introducing a novel, data-driven, machine learning– and knowledge-enhanced methodology to predict post-disaster building demolition, reconstruction, and vacancy probabilities. Leveraging unique three-year, seven-wave longitudinal field data from the 2021 Midwest tornado outbreak, our framework integrates multi-dimensional impact factors, with a pioneering focus on socioeconomic vulnerability metrics derived from geospatial data. The key contribution lies in providing the first quantitative framework to decipher the “to-demolish-reconstruct-or-not” decision pathway after disasters. This methodology is designed for seamless integration with established community recovery models, thereby offering critical scientific support for post-disaster risk assessment, resource allocation, and evidence-based resilience policy formulation across all potential recovery scenarios.

Speaker



Sai Kiran Simhadri

Graduate Student | Old Dominion University

ID 365: Using Open-source LLMs for Construction Information Retrieval

2:55 PM – 3:15 PM

Author(s): Bozhou Zhuang, University of California, Los Angeles (UCLA); Sriram Narasimhan, University of California, Los Angeles (UCLA); Eric Goldwyn, New York University (NYU); Elif Ensari, New York University (NYU)

Construction projects generate large volumes of reports and data, which create challenges for effective information retrieval and synthesis. This study developed an open-source large language model (LLM)-based framework for construction information retrieval. A retrieval-augmented generation (RAG) system was developed and evaluated using ten years of publicly available monthly reports from a major transit construction project in California. By integrating embedding models with open-source LLMs, the framework enables accurate question answering based directly on retrieved chunks from the vectorized database. Quantitative evaluation indicates that the system achieves over 85% accuracy in retrieving relevant information and generating correct responses. In addition, a multi-agent architecture was developed to support higher-level reasoning and decision support. The three agents are: a query agent for year-specific question answering with RAG system, a writing agent that summarizes yearly responses, and a validation agent that evaluates and compares summaries generated by different LLMs and recommends the most reliable model. This agent-based framework supports both detailed information lookup and strategic overview tasks commonly required in construction management. This study demonstrates that engineers and stakeholders can access important construction project information without the need to manually review the document with open-source LLMs. Overall, the proposed framework improves the autonomy of construction management processes.

Speaker



Bozhou Zhuang

UCLA

ID 411: Multistable Surface using Elastic Snap-Through Mechanisms for Smart Facades

3:15 PM – 3:35 PM

Author(s): Moneef Mohamed Elobaid Musa, Iowa State University; Anna E Jaeger, University of St Thomas; Andrea Camacho-Betancourt, University of Florida; Zihan Li, University of Florida; Ayodele Iyanalu, Iowa State University; Thomas W Secord, University of St Thomas; Rob Whitehead, Iowa State University; Minhee Kim, University of Florida; Iris V Rivero, University of Florida; Simon Laflamme, Iowa State University; Han Liu, Iowa State University

Smart adaptable building facades offer a promising approach for creating building envelopes that can adjust to changing environmental and functional conditions while maintaining energy efficiency, structural stability, and architectural integrity. This paper investigates a reconfigurable facade surface composed of repeating transformable elements capable of achieving and maintaining multiple stable shapes. The proposed facade system consists of assembled bistable units connected through compliant joints. Shape changes are enabled by elastic snap-through of curved beam members, a nonlinear mechanical mechanism that allows the surface to transition between distinct configurations and remain locked in each state without continuous energy input. Such behavior is particularly attractive for facade components, including sunshades, rain screens, and thermal or vapor barriers—that can benefit from responding to variations in wind, daylight, temperature, and humidity. Design development and optimization were supported through prototyping using fused deposition modeling with flexible polylactic acid. Mechanical behavior was experimentally evaluated by applying quasi-static in-plane displacements at the boundaries of the module to trigger snap-through of the curved elements. The experiments demonstrated repeatable and stable transitions between configurations, and reliable passive shape retention once each state was reached. The surface was observed to transform from an initially near-flat geometry into multiple curved forms with clearly defined and stable locked-in shapes. Overall, the results highlight the potential of multistable, additively manufactured surfaces as low-energy adaptive facade systems. By combining mechanical robustness with minimal actuation requirements, the proposed multistable facade concept offers a scalable and energy-efficient solution for next-generation smart building envelopes.

Speaker



Moneef Mohamed Elobaid Musa

Iowa State University

MS 069: Uncertainty Quantification and System Reliability Methods for Regional Risk and Resilience Assessment

2:15 PM – 3:35 PM | Location: GUGG 205

Chair(s): Sang-ri Yi; Ziqi Wang; Ji-Eun Byun; Alexandros Taflanidis

Moderatorss



Sang-ri Yi

Assistant Professor | Rice University



Ji-Eun Byun

Assistant Professor | Imperial College London

ID 705: A Multi-Scale Framework for Regional Seismic Risk Analysis via Random-Field Renormalization

2:15 PM – 2:35 PM

Author(s): Sebin Oh, University of California, Berkeley; Ziqi Wang, University of California, Berkeley

Citywide damage patterns that extend far beyond individual structures under major earthquakes demand regional risk assessment that remains informative across decision scales. Yet practitioners must routinely choose between building-resolved information and aggregated metrics (e.g., district-level functionality), making it essential to understand how collective response patterns evolve under spatial aggregation. Building on recent evidence that regional structural damage can exhibit phase-transition behavior—shifting from largely safe to largely damaged as hazard intensity increases, while structural-property diversity smooths the transition—we propose an renormalization group (RG)-inspired, scale-consistent probabilistic framework for regional seismic risk.

To enable meaningful coarse-graining on irregular building layouts, we adopt a continuous approximation in which building-level damage is represented by a spatial random field conditioned on local intensity measures. Starting from building-level simulation ensembles, we define a decision-relevant coarse-graining operator that aggregates adjacent components into progressively larger spatial units (e.g., blocks, neighborhoods, districts), producing a sequence of scale-indexed damage-fraction fields. This construction enables direct comparisons of decision variables across scales, including exceedance probabilities of regional damage fractions, the likelihood of “collectively safe” versus “collectively damaged” states, and spatial clustering of severe damage.

As a baseline at each scale, we calibrate a Gaussian random field (GRF) with kernel-based spatial dependence to capture correlations induced by shared hazard excitation and spatially correlated vulnerabilities. To represent non-Gaussian features that are critical for risk-informed decisions—such as heavy-tailed outcomes and extreme clustering—we refine the GRF using a neural operator that maps the calibrated Gaussian field to a non-Gaussian field while preserving spatial structure. The operator is trained to reproduce empirical joint statistics from the regional simulations, including marginal distributions and tail-dependent clustering, enabling efficient multiscale risk evaluation and scenario generation.

Applied to a residential area in San Francisco with over 15,000 buildings, the framework shows that aggregation can amplify decision polarization (collective survival under smaller events versus collective collapse under larger events) by suppressing microscopic variability. Meanwhile, a near scale-invariant regime emerges around $M_w \approx 7.0$, where decision variables remain relatively stable across aggregation levels, consistent with RG intuition.

Speaker



Sebin Oh

Graduate Student | University of California, Berkeley

ID 785: Integrated Framework for Load Factor Calibration and System Reliability Assessment of Hydraulic Steel Miter Gates

2:35 PM – 2:55 PM

Author(s): Shweta Shrestha, Colorado State University; Hussam Mahmoud, Vanderbilt University; Christine Lozano, USACE-ERDC

Miter gates are critical hydraulic steel structures that enable navigation along inland waterways. These structures face significant deterioration from corrosion, fatigue, and dynamic loading events, yet their inherent structural redundancy allows them to withstand localized failures through load redistribution. Traditional reliability approaches, which focus on first-member failure, often prove overly conservative for such redundant systems and fail to capture the true system-level failure mechanisms. This research presents an integrated computational framework that combines probabilistic load characterization with system reliability theory to advance the state of practice in miter gate design and assessment.

The first component of this framework addresses the calibration of load factors for barge impact events, a critical and highly uncertain loading scenario for miter gates. Leveraging Automatic Identification System (AIS) traffic data from MarineCadastre.gov, barge velocities and flotilla configurations were statistically characterized for multiple lock locations across the inland waterway system. These distributions were propagated through the USACE bilinear impact force model to generate probabilistic representations of impact forces. A two-stage calibration procedure was employed: First-Order Reliability Method (FORM) provided initial estimates of load factors, followed by an optimization-based approach that minimizes deviations from target reliability indices across multiple load combinations and limit states. The resulting load factor for barge impact are shown to be consistent with existing USACE design philosophy while being grounded in real-world traffic statistics and formal reliability theory.

The second component extends this probabilistic foundation to system-level reliability assessment through progressive failure simulation and minimal cut-set analysis. A three-dimensional finite element model of a representative miter gate was developed incorporating primary girders, skin plates, and boundary conditions consistent with USACE guidance. Progressive failure was simulated by iteratively degrading or removing structural members upon exceeding defined limit states, allowing loads to redistribute through alternate paths until system failure criteria were met. From these physics-based failure simulations, minimal cut sets, the smallest combinations of member failures that cause system collapse, were automatically identified. These cut sets were then integrated into a formal system reliability framework where each cut set forms a parallel subsystem, and the collection of cut sets operates in series. System-level probability of failure was quantified using FORM or Monte Carlo simulation with uncertainties in material properties, corrosion-induced section loss, and loading conditions explicitly modeled.

This integrated framework provides multiple contributions to the field. First, it establishes a data-driven, reliability-consistent approach to load factor calibration for dynamic events that can be extended to ice and debris impact. Second, it creates a formal linkage between finite element progressive failure behavior and cut-set system reliability theory, moving beyond component-level analysis to capture true system failure mechanisms. Third, it generates reliability-based criticality maps that rank structural members by their contribution to system failure probability, directly supporting risk-informed inspection and maintenance planning. The framework demonstrates that system reliability assessment must account for load redistribution and progressive damage to avoid both overly conservative design and underestimation of actual failure risk.

Speaker



Shweta Shrestha

ID 212: AI-based Causal Analysis of Infrastructure Networks under Shifting Conditions for System Reliability Assessment and Intervention Planning

2:55 PM – 3:15 PM

Author(s): Rayeon Kim, Seoul National University; Youngjun Kwon, The Ohio State University; Junho Song, Seoul National University

Service disruptions in civil infrastructure networks such as power, water, transportation, and communications often indicate that operating rules, environmental conditions, or hazard combinations have shifted away from historical patterns. At the regional scale, these networks exhibit complex and sensitive interdependencies, where disruptions can propagate nonlinearly and lead to disproportionate impacts across the system. Therefore, rare but high-impact disruption scenarios, referred to as black swan events, require proactive management. However, existing approaches for system interdependency modeling and cascading failure risk analysis still rely on historical disaster records, fixed dependency maps, or correlation-based estimates that may fail when conditions move beyond the historical range. These historically constrained data-driven approaches make it difficult to quantify black swan risk or select preventive actions when failures occur in new combinations, simultaneously, or in an unfamiliar sequence. To address these limitations, this study proposes an artificial intelligence-driven reliability assessment framework that emphasizes prevention of rare but physically feasible compound disruptions beyond point prediction. The framework infers causal relationships among network components from routine operational data and continuously monitors changes in these interactions, providing early warning signals when standard prediction models become unreliable because of shifting conditions of causal patterns. Upon detection of such shifts, system-level failure probability is estimated while allowing for missing data and hidden factors, and an upper bound on service failure probability is provided to avoid underestimation under new conditions.

Interventions strategies including targeted isolation – operational control changes, or recovery prioritization – are then prioritized to block likely propagation pathways and reduce the upper bound through causal reasoning. Numerical examples demonstrate that the proposed framework enables proactive, resilience-informed intervention planning to limit cascading failures and mitigate unexpected damage, even under unprecedented compound events. To address the scarcity of black swan records, feasible scenarios are generated under domain constraints and the learned interaction structure, and candidate interventions are evaluated based on their effectiveness in reducing system-level risk across this scenario set.

Speaker



Rayeon Kim

Graduate Student | Seoul National University

ID 483: Probabilistic Wildfire Spread Forecasting with Sequential Bayesian Updating using Physics-Based Fire Spread Simulator and Satellite Observations

3:15 PM – 3:35 PM

Author(s): Youngjun Kwon, The Ohio State University; Abdollah Shafieezadeh, The Ohio State University

Severe wildfires increasingly impose substantial human, ecological, and economic losses, underscoring the importance of timely forecasting for effective response, resource allocation, and risk mitigation. This need is becoming more acute as agencies are increasingly required to manage multiple fires concurrently, yet reliable forecasting remains difficult because fire dynamics are complex and highly sensitive to rapidly changing weather and fuel conditions. Fire spread simulators provide a mechanistic basis for prediction, but performance can degrade when governing parameters are treated as static or only weakly constrained during an event. At the same time, remote sensing provides timely evidence of ongoing fire evolution, but integrating these observations with simulation in a statistically consistent way is challenging because observation characteristics vary across sensors and acquisitions are often asynchronous with non-negligible latency. To address these gaps, this study develops a probabilistic, data-assimilative wildfire spread forecasting framework that couples a fire spread simulator with sequential Monte Carlo. The framework updates both the evolving fire state and a compact set of physically interpretable governing parameters as new observations arrive, maintaining consistency between modeled evolution and observed progression while preserving interpretability. Sensitivity-informed screening is used to identify the parameters that most strongly influence spread patterns under coupled weather–fuel effects, emphasizing wind speed and direction, ambient temperature, fuel-driven modulation of propagation, and directional rates of spread that evolve along each wildfire spread direction. Building on this identification, a Rao-Blackwellized particle filter is employed to propagate an ensemble of stochastic spread realizations forward in time and to refine the posterior distribution by evaluating the time-varying mismatch between simulated and observation-informed fire evolution. By carrying inferred parameter uncertainty forward through continued simulation, the approach produces probabilistic predictions of future fire growth, including spatial likelihood fields that represent where and when growth is most plausible rather than a single deterministic trajectory. The framework is demonstrated and validated on a California wildfire case study using fire evolution records from multiple satellite sensors with different spatial and temporal resolutions. Beyond forecasting, the posterior parameter estimates with quantified uncertainty in the fire spread simulator can be utilized to provide interpretable diagnostics for adaptive response strategies.

Speaker



Youngjun Kwon

Postdoctoral Scholar | The Ohio State University

MS 070: Probabilistic assessment, data-driven inference, and optimization for decision-making under uncertainty

2:15 PM – 3:35 PM | Location: ECON 119

Chair(s): Kostas G. Papakonstantinou; Charalampos P. Andriotis; Dan M. Frangopol; George Deodatis

Moderators



Kostas Papakonstantinou

Associate Professor | Penn State University

ID 892: On the use of stochastic simulation-optimization to improve EMS dispatch strategies

2:15 PM – 2:35 PM

Author(s): Sevin Mohammadi, Columbia University; Antonina Kosikova, Columbia University; Derek Long, Columbia University; Javad Ghorbanian, University of Southern California; Andrew Smyth, Columbia University; Henry Lam, Columbia University; Audrey Olivier, University of Southern California

Emergency medical services (EMS) are a critical piece of our infrastructure, providing medical care on the scene of incidents and transporting patients to hospitals. EMS operations involve high-stakes decisions with cascading effects, from ambulances pre-positioning to dispatch and hospital transports, while facing a variety of environmental and operational uncertainties. Stochastic simulation presents an interesting avenue to both design optimal policies and decisions, via simulation-optimization, and to assess their effect in a probabilistic manner. In this talk we present an early version of a probabilistic digital shadow of EMS, informed by real-life EMS data from a dense urban environment, and its application to the design of novel dispatch policies. We discuss the importance of considering both aleatory and epistemic uncertainties during training of the various probabilistic predictors involved in the simulator, e.g. ambulance travel time, incidents occurrence, hospital turn-around time etc. We also present results of a novel heuristics dispatch strategy, which penalizes dispatches from high-demand low-coverage areas for low-acuity incidents to preserve resources for high-priority emergencies. The parameterized dispatch rule is optimized via simulation-optimization, and stochastic simulation also allows a robust probabilistic assessment of outcomes. Overall, this talk a proof-of-concept application of probabilistic data-driven modeling and stochastic simulation(-optimization) to a high-stakes decision-making framework.

Speaker



Audrey Olivier

Dr | University of Southern California

ID 420: A Time-Varying Observation Model for POMDP-Based SHM

2:35 PM – 2:55 PM

Author(s): Junyi Li, Department of Civil, Urban and Environmental Engineering, Center for Urban Science and Progress, New York University, United States of America; Eleonora Maria Tronci, Department of Civil, Urban and Environmental Engineering, Center for Urban Science and Progress, New York University, United States of America

While Structural Health Monitoring aims to enhance structural reliability and operational resilience of critical infrastructure by transitioning toward condition-based maintenance; the practical efficacy of these systems is often compromised by low quality data and sensor information. Originating from transducer degradation, environmental volatility, and transmission interference, this noise typically manifests as a non-stationary process with complex, time-varying characteristics that compromise the inferential fidelity of structural observations. Consequently, SHM strategies would benefit from optimized, targeted interventions aiming to update the confidence level in data and measurement collections. These newly updated high-fidelity observations would play a critical role in resolving uncertainty and dynamically recalibrating the observation model when the reliability of passive sensors degrades.

Partially Observable Markov Decision Processes (POMDPs) provide a framework for optimizing inspection and maintenance policies to achieve cost-effective decision-making without compromising safety. Yet, standard POMDP formulations typically assume stationary and known observation noise, and the observation model is not updated during operation. This simplification overlooks the complex and evolving nature of noise in monitoring data, causing belief updates to become overconfident and leading to suboptimal, locally optimal maintenance policies. To address this challenge, the study proposes a POMDP-based framework that incorporates a dynamic and learnable observation model. The framework accounts for temporally dependent measurement noise and systematically leverages inspection observations to validate and adapt sensor reliability. This adaptive observation model enables the agent to learn evolving noise characteristics over time, thereby enhancing long-run decision quality and robustness in sequential decision-making. Across simulations of bridge structural deterioration and comparative evaluations under multiple sensor noise regimes, our method demonstrates enhanced policy robustness and improved maintenance decision quality when compared with traditional POMDP formulations that assume fixed observation noise.

Speaker



Junyi Li

Phd Student | New York University

ID 909: Interpretable Deep Reinforcement Learning for Element-level Bridge Life-cycle Optimization

2:55 PM – 3:15 PM

Author(s): David Yang, Portland State University; Seyyed Amirhossein Moayyedi, Portland State University

The new Specifications for the National Bridge Inventory (SNBI), in effect from 2022, emphasize the use of element-level condition states (CS) for risk-based bridge management. Instead of a general component rating, element-level inspection results use an array of CS quantities to represent the condition of a bridge. Although this greatly increases the granularity of the bridge condition, it introduces challenges to set up optimal life-cycle policies due to the expanded state space from one single integer to four-dimensional probability arrays. This study proposes a new interpretable deep reinforcement learning (XDRL) algorithm to seek optimal maintenance policies based on element-level state representations. Compared to existing DRL methods, the proposed algorithm yields maintenance policies in the form of oblique decision trees with minimal nodes and depth, making them directly understandable and auditable by humans and easily implementable into current bridge management systems. To obtain near-optimal policies, the new algorithm includes three major improvements to existing DRL methods: (a) the use of differentiable soft tree models as actor function approximations, (b) regularization with pruning rules to limit policy complexity, and (c) a temperature annealing process during training to allow post-training conversion from a probabilistic soft tree to a deterministic oblique decision tree. The benefits and trade-offs from these techniques are demonstrated in both supervised and reinforcement learning settings. The resulting XDRL algorithm is then illustrated in a life-cycle optimization problem for deteriorating steel girder elements.

Speaker



David Yang

Assistant Professor | Portland State University

ID 930: Integrating Pre-Posterior Analysis and POMDPs for Engineering Decisions

3:15 PM – 3:35 PM

Author(s): Kostas G. Papakonstantinou, The Pennsylvania State University; Pablo G. Morato, Technical University of Munich; Charalampos P. Andriotis, Technical University of Delft

Design, management, and operational decisions in engineering are regularly made under uncertainty, where latent system properties evolve stochastically over time, and observations/data are partial, noisy, and sometimes expensive to acquire. Such engineering decision problems, sequential or not, are traditionally approached through pre-posterior decision analysis, represented as decision trees that are often simplified in practice to restricted heuristic policy classes due to dimensionality challenges. Pre-posterior analysis has also close ties to value-of-information (VoI) and related metrics, often treated, however, as a relevant but auxiliary direction. In this work, we formally establish that pre-posterior analysis is essentially equivalent to partially observable Markov decision process (POMDP) formulations, benefiting from all the advantageous POMDP attributes. As a result, (i) no policy restrictions and decision space limitations are needed, (ii) all value-of-information (VoI) arguments can now directly and naturally emerge from the POMDP solution, and (iii) scalability can be tackled through dedicated POMDP and reinforcement learning-based solvers.

Overall, we explicitly map decision-theoretic primitives to POMDP components and nomenclature. Under this mapping, the belief state is defined as the posterior distribution over latent conditions given the action–observation history. It serves as sufficient statistics for dynamic decision-making by compressing the entire past into a state representation on which optimal decisions can be based. The resulting POMDP recursion matches the Bellman update over beliefs, and we showcase that the pre-posterior analysis tree-based backward induction is dynamic programming written in an unrolled form. We also explain how this POMDP perspective makes VoI intrinsically quantified, and information is valued exactly through its effect on belief updates and their connection to the POMDP value function. To relate modeling conventions used across communities, we also show how pre-posterior and POMDP sequential decision orderings can be reconciled, without changing the underlying decision problem.

Our unified formulation is ultimately illustrated through a set of case studies that further clarify the theoretical connections and the associated computational trade-offs. We start from a classical pile selection problem cast in pre-posterior form, which offers an intuitive interpretation of belief updating, and then move on to a simplified inspection and maintenance problem that can still be solved by backward induction. The focus then shifts to component-level planning under partial observability, where the curse of history makes explicit tree enumeration impractical and instead motivates point-based POMDP solvers operating directly on the belief space. Finally, system-level planning for multi-component systems highlights the curse of dimensionality, for which scalable approximations based on multi-agent reinforcement learning are required, while preserving the same underlying decision-theoretic structure. Overall, the presented unified formulation proves that the classical and notable sequential pre-posterior analysis provides a mathematically equivalent problem statement as POMDP planning, for which belief-state recursions and modern solvers enable reliable decision support at scale.

Speaker



Kostas Papakonstantinou

Associate Professor | Penn State University

MS 076: Advances in Modeling Wind and Its Effects on the Built Environment

2:15 PM – 3:35 PM | Location: CHEM 140

Chair(s): Teng Wu; Catherine Gorle; Marco Giometto

Moderators



Catherine Gorle

Associate Professor | Stanford University

ID 626: Automating ASCE 7-22-Informed Pressure Tap Layouts for Efficient Wind Tunnel Testing of Low-Rise Buildings

2:15 PM – 2:35 PM

Author(s): Robyn Andrews, Texas A&M University; Stephanie Paal, Texas A&M University; Dejiang Chen, Florida International University; Arindam Chowdhury, Florida International University

Wind tunnel studies of low-rise buildings remain a primary means of quantifying wind-induced pressures and informing design provisions for the built environment. The development of pressure tap layouts is a necessary step in experimental planning that requires careful judgment to balance spatial resolution, instrumentation limits, and fabrication effort. In current practice, these layouts are typically developed manually using ASCE 7 principles as qualitative guidance, supplemented by the experience of wind engineers who adjust layouts based on previously tested, geometrically similar configurations. While effective, this approach requires substantial manual effort and relies on case-by-case judgment, which can make it challenging to apply consistently or efficiently across large parametric experimental studies.

This work presents a geometry-aware, automated pressure tap layout tool intended to support wind engineers during the experimental planning phase. The framework formalizes the zoning concepts presented in ASCE 7-22 Fig. 30.3-2 (A–G) and translates them into a repeatable process for generating pressure tap distributions directly from basic building descriptors, including roof geometry, roof slope, effective height, model scale, and roof type. The ASCE 7 zoning diagrams serve as a physics-informed basis for identifying regions where higher wind pressures are expected on residential structures. Rather than prescribing uniform spacing, the tool enforces tighter spacing in these higher-demand regions—such as corners, edges, and ridge-adjacent zones—while allowing progressively coarser spacing in lower-demand interior regions in a manner consistent with roof-type-specific zoning definitions. This approach reflects the spatial concentration of peak pressure gradients observed in low-rise wind loading and enables more efficient allocation of measurement resolution.

The tool serves as a flexible and practical planning aid, allowing users to control candidate spacing options, impose tap-count limits, and generate outputs compatible with wind tunnel fabrication and instrumentation workflows. Application of the tool to a dataset of 55 distinct roof geometries demonstrates its ability to rapidly produce consistent, code-informed tap layouts across a wide range of configurations without manual iteration. The automated approach reduces ad hoc decision-making in tap placement, improves repeatability across experimental campaigns, and significantly shortens the time required to move from conceptual test design to fabrication-ready layouts.

By embedding established ASCE code-based zoning logic into experimental planning, this tool is intended to serve as a reusable resource for the wind engineering community. Its use has the potential to support more efficient wind tunnel campaigns, facilitate large-scale systematic studies of wind effects on the built environment, and improve the consistency of experimental datasets used in research and future code development.

Speaker



Robyn Andrews

PhD Student | Texas A&M University

ID 811: Revisiting Modified Ibarra-Medina-Krawinkler Model for Hysteretic Restoring Forces of RC Frame Building Components under Hurricanes

2:35 PM – 2:55 PM

Author(s): Baichuan Deng, University at Buffalo; Teng Wu, University at Buffalo

The performance-based wind design (PBWD) methodology for buildings allows for controlled nonlinear responses in structural components. Within PBWD framework, the nonlinear response history analysis (NRHA) is a critical tool for evaluating structural performance under extreme wind hazards (e.g., hurricanes). The computational cost of wind-induced NRHA could be extremely high due to its small time steps and long simulation duration. The hysteretic restoring-force models for structural components are typically leveraged to improve the computational efficiency. However, these structural component-level hysteretic models with lumped plasticity are predominantly developed for seismic-induced NRHA and calibrated using seismic-based experimental data. Compared to the seismic loading, the hurricane wind loading is characterized by long duration, evolving directionality, and sustained mean-load effects. It is expected that these models may be generally inadequate for capturing hurricane wind-induced nonlinear structural behavior. This limitation is particularly significant for reinforced concrete (RC) structures, whose nonlinear response is governed by complex, path-dependent material behavior involving cracking, crushing, reinforcement yielding, and bar-concrete interaction. To address this gap, this study revisits the modified Ibarra-Medina-Krawinkler (IMK) model for capturing hurricane-specific hysteretic restoring forces of RC columns and beams. In the first stage, hurricane wind loading protocols are derived by conducting NRHAs on representative RC building archetypes subjected to synthetic hurricane wind histories that explicitly capture event duration and the time-varying wind speed and direction. Rainflow cycle counting is employed to extract loading cycles, and a fatigue theory-based equivalent cycle range modification is introduced to account for the mean-load effects. In the second stage, high-fidelity finite element models (FEMs) of RC frame components (columns and beams) are built in Abaqus using solid elements capable of explicitly representing cracking and crushing (with a concrete damaged plasticity model), material deterioration (with fracture-energy-based tension softening) and bar-concrete interaction (with cohesive elements), and validated using experimental data. Based on the validated FEMs, geometric and detailing variables are predefined to generate the component behavior dataset, namely axial-load ratio, span-to-depth ratio, slenderness and reinforcement ratio. Leveraging the high-fidelity FEMs results (along with available tests), the feature-importance analysis is conducted to identify the key variables controlling hysteresis and then the modified IMK model is re-calibrated with the FEM data. The proposed two-stage framework enables practical and computationally efficient concentrated-hinge modeling of RC frame buildings in wind-induced NRHA while explicitly accounting for hurricane-specific cyclic degradation. The outcomes of this research provide a critical modeling foundation and guideline for advancing PBWD of RC structures subjected to hurricane wind hazards.

Speaker



Teng Wu

Prof. | University at Buffalo

ID 629: Development of Loading Protocols for Testing Solar Tracker Components under Synoptic and Thunderstorm Winds

2:55 PM – 3:15 PM

Author(s): Mahmoud Elnahla, Colorado State University; Yanlin Guo, Colorado State University; Teng Wu, University at Buffalo

With the adoption of larger PV modules and lighter frame profiles, solar-tracker systems have become more flexible and more sensitive to wind-induced loading. Field observations indicate that solar-tracker systems are increasingly susceptible to deterioration and possible failure under cumulative cyclic deformation demands at structural interfaces, including purlins, module frames, clamps, and fasteners. These failures are governed by cumulative damage associated with repeated cyclic loading, with deterioration and possible failure controlled by inelastic excursions. Existing standards, such as IEC TS 62782, are intended to assess the durability of internal PV module elements (e.g., solar cells and interconnect ribbons) through cyclic uniform pressure loading. However, they do not provide loading protocols that represent the number and amplitudes of cycles governing cumulative damage under realistic wind excitation, nor do they explicitly address the performance of tracker structural components subject to cyclic inelastic deformation.

To address this gap, this study proposes a wind-induced cumulative-damage-based cyclic loading protocol for solar trackers based on statistical analysis of long-term surface wind observations from the Automated Surface Observing System (ASOS). The number and amplitudes of cycles applied to a component are derived from statistical evaluation of cyclic response histories obtained from the finite element model of a representative tracker system subjected to representative synoptic and thunderstorm wind events. The resulting cyclic demands are quantified using a cumulative damage model, such as Miner's rule, that relates the number and amplitudes of load cycles to progressive deterioration and eventual failure under cyclic loading. This damage-based assessment is then employed to define a variable-amplitude cyclic loading history that statistically reflects the representative accumulation of damage, while incorporating the maximum demand-to-capacity ratio considered in the design.

The resulting cyclic load histories are intended to support the development of quasi-static cyclic tests for the assessment of deterioration and failure under cyclic loading, with damage governed by inelastic excursions, and to provide representative input demands for numerical simulation of solar-tracker components. In this manner, the protocol provides a physically and statistically grounded basis for evaluating cumulative damage, and ultimate system failure, and for establishing appropriate demand-to-capacity measures for the reliable design of next-generation solar-tracker systems.

Speaker



Mahmoud Elnahla

Mr | Colorado State University

ID 650: Wind-Induced Base Shear and Torsion in Low-Rise Flat-Roof Buildings with Irregular (Non-Rectangular) Plans

3:15 PM – 3:35 PM

Author(s): Mahmoud Abdallah, Florida International University; Omar Abdallah, Florida International University; Rani Al Sayegh, Florida International University; Ioannis Zisis, Florida International University

Irregular (non-rectangular) plan geometries in low-rise buildings can generate asymmetric pressure fields and torsional demands that are not well represented by the rectangular-building proxies adopted in current wind codes and standards. This study quantifies plan-geometry and height effects on wind-induced base shear and torsion using directional pressure measurements on rigid, flat-roof building models tested at 1:50 scale at the NHERI Wall of Wind (WOW) Experimental Facility. Three plan shapes (rectangular, L-shaped, and T-shaped) and three height configurations representing one-, two-, and three-story buildings are considered, yielding a nine-case matrix. External wall pressure taps provide wall pressure time histories, which are integrated over tributary areas to derive global base shear components and torsional base moment about the plan centroid. Directional peak load effects are extracted for each wind direction and summarized using peak coefficients and controlling directions to enable consistent comparisons across geometries and heights. Results indicate that plan geometry strongly governs torsion: L-shaped footprints produce the largest directional torsional envelopes, T-shaped footprints exhibit intermediate response, and the rectangular plan bounds the lower range. Peak torsion is generally controlled by oblique winds that engage re-entrant corners or projecting wall segments, whereas changes in base shear due to irregularity are comparatively modest once directionality is accounted for.

Speaker



Mahmoud Abdallah

Research Assistant - Ph.D. Candidate | Florida International University

MS 088: Advances in Damage Mechanics and Micromechanics - in Honor of the 2025 Blaise Pascal Medal in Engineering to Professor Jiann-Wen Woody Ju

2:15 PM – 3:35 PM | Location: UMC 247

Chair(s): Huiming Yin; Lizhi Sun; Glaucio Paulino; Yong-Rak Kim

Moderators



Yong-Rak Kim

Professor | Texas A&M University

ID 804: Towards a Plasticity-Based Fatigue Damage Model for Asphalt Binder

2:15 PM – 2:35 PM

Author(s): Haifang Wen, Washington State University

Fatigue cracking is one of the major distresses in asphalt pavement. In past studies that characterize the fatigue mechanism of asphaltic materials, plasticity has been considered independent of damage. However, the plasticity of asphalt binders significantly impacts the fatigue performance and service lifetime of asphalt pavement. The primary objective of this paper is to develop a plasticity-based fatigue damage model for asphalt binders to predict complex fatigue behaviors. An innovative experimental approach was used to integrate creep tests with unidirectional cyclic tests. Perzyna's viscoplastic model that incorporates the Drucker-Prager yield function is proposed to capture the asphalt binders' stress state and viscoplastic response. The Kachanov-Rabotnov damage evolution law is applied to predict the viscoplastic damage evolution of asphalt binders. The proposed model is validated by extensive experimental data under various loading paths at different temperatures. The results indicate that the plasticity-based fatigue damage model exhibits robust effectiveness in capturing the viscoplastic damage evolution of asphalt binders under various loading paths. Validation results demonstrate that the viscoplastic damage strain of asphalt binders under various loading paths of cyclic loading tests can be accurately predicted based on the model determined by long-term creep test results, with correlation coefficients (R^2) exceeding 0.89. This integration highlights the model's versatility and applicability in practical scenarios, providing a reliable tool for understanding and predicting asphalt binder's behavior under diverse loading conditions.

Speaker



Haifang Wen

Professor | Washington State University

ID 805: A localizing gradient damage model for the dynamic fracture of quasi-brittle materials with strain rate dependency

2:35 PM – 2:55 PM

Author(s): Leong Hien Poh, National University of Singapore

This presentation focuses on the dynamic fracture of quasi-brittle materials such as concrete under different loading rates. A simple form of damage model is considered with the necessary constitutive relations to model the dynamic fracture responses under mixed mode loading conditions. It is shown that the introduction of strain rate dependency in the constitutive model can induce numerical instability. This motivates a modified numerical implementation approach for the strain rate effect in the constitutive model. Validation of the model's capabilities is demonstrated through several examples as reported in the literature.

Speaker



Leong Hien Poh

Prof | National University of Singapore

ID 869: An Integrated iBEM-Neural Network Framework for Rapid Detection of Structural Defects or Inhomogeneities

2:55 PM – 3:15 PM

Author(s): Jinming Zhang, COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK; Huiming Yin, COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

This study addresses the inverse problem of identifying 3D spherical inclusions in elastodynamic structures by combining a deep neural network (DNN) with Inclusion-Based Boundary Element Method (iBEM). iBEM is employed for multi-scale virtual experiments to capture both local-scale inhomogeneity interactions and macro-scale boundary effects. Material mismatches are modeled through eigenfields that generate a mesh-free internal domain, providing compact boundary data suitable for machine learning. Frequency-based features and specimen symmetry enable the refinement of full boundary data into sparse critical-points, which represent sparse sensor locations. A physics-informed deep neural network is trained on frequency-domain responses sampled at sparse sensor locations, mapping them to inclusion parameters such as location, radius, and material contrast. This network architecture employs multiple hidden layers with rectified linear unit (ReLU[Y1.1]) activation function, dropout regularization, and batch normalization to ensure robust generalization. The system enables real-time inference, offering a scalable and sustainable approach to structural health diagnostics with minimal sensor deployment.

Keywords: Inverse problem, Deep Neural Network, Physics-informed Machine Learning, Eshelby's Equivalent Inclusion Method, inclusion-based Boundary Element Method, Harmonic Excitation.

Speaker



Jinming Zhang

Ph.D. | Columbia University

ID 873: Effective multi-physical behavior of a lattice with defects

3:15 PM – 3:35 PM

Author(s): Huiming Yin, Columbia University

The recently developed singum model homogenizes a lattice into a continuum with effective material properties. When the lattice material is subjected to a uniform flow load on the boundary, the load transfers through the links between the neighboring nodes; while its overall response can be described by the corresponding constitutive law for a periodic lattice. The singum model provides the analytical form of multiphysical properties. When defects exist, the singum model still uses the Voronoi decomposition to transform the lattice to a continuum with singum particles but the singum properties may not be uniform anymore in the neighbor of defects. The load transfer can be solved by an inhomogeneity problem with the Green's function technique at the continuum level and then map to the lattice with the singum model. This application of this framework to mechanical and multiphysical problems will be discussed.

Speaker



Huiming Yin

Associate Professor | Columbia University

MS 037: Shaping Tomorrow: State-of-the-Art Innovations in Advanced Cementitious Materials and Concrete Technologies

2:15 PM – 3:35 PM | Location: UMC 415-417

Chair(s): Jianqiang Wei; Sung-Hwan Jang; Linfei Li; Yen-Fang Su

Moderators



Jianqiang Wei

Assistant Professor | University of Maryland

ID 360: Quantifying Washout and Surface Defects in Underwater 3D Concrete Printing with AI-Enabled Image Analytics

2:15 PM – 2:35 PM

Author(s): Yen-Fang Su, Louisiana State University and Agricultural and Mechanical College; Nasser Mohammed, Louisiana State University and Agricultural and Mechanical College; Masoud Pasbani, Louisiana State University and Agricultural and Mechanical College

As research in underwater 3D concrete printing (U3DCP) advances, the need for reliable methods to quantify print quality has become increasingly important. A reproducible quality score that enables clearer evaluation of how additives and printer parameters influence material performance is needed. However, conventional printability metrics developed for in-air printing do not capture U3DCP-specific surface degradation mechanisms, including washout-driven material loss, surface tearing, and crack-like discontinuities that form during submerged deposition. This study presents an AI-assisted, image-based characterization framework that converts top-down photographs of standardized test prints into a quantitative quality score using four sequential modules: (1) print extraction via automated segmentation to isolate the deposited geometry from the background; (2) defect characterization to localize discontinuities such as voids, tearing, and crack-like features; (3) boundary irregularity measurement to quantify edge roughness and filament instability; and (4) washout assessment to estimate surface erosion and loss of geometric fidelity attributable to underwater exposure. To ensure robust defect quantification, we benchmark conventional computer-vision approaches (e.g., thresholding, edge/contour analysis, morphology) against supervised machine-learning methods, highlighting the tradeoffs in accuracy, interpretability, and generalization across lighting and turbidity conditions. Dataset construction is enabled by a human-in-the-loop labeling workflow that iteratively combines expert annotations with model-in-the-loop correction to improve consistency and reduce labeling burden. Each module outputs a normalized metric designed to be interpretable and comparable across experiments, with lower values indicating higher-quality prints. Finally, the dataset along with the trained model can be used for benchmarking and transfer learning to enable reproducible, cross-lab comparison and rapid adaptation of in-situ quality assessment for U3DCP.

Speaker



Yen-Fang Su

Assistant Professor | Louisiana State University

ID 430: Embedded CNRP Bars for Real-Time Structural Health Monitoring of Concrete Structures

2:35 PM – 2:55 PM

Author(s): Ga-Hyeon Eom, Hanyang University; Yu-Jin Jung, Hanyang University; Sung-Hwan Jang, Hanyang University

Structural failures in concrete structures, such as bridges and tunnels, can cause substantial economic losses and safety risks, underscoring the need for reliable, continuous structural health monitoring (SHM). However, current practice still relies largely on periodic visual inspections, which are qualitative, inspector-dependent, and unsuitable for real-time monitoring. To address these limitations, this study develops carbon nanotube-reinforced polymer (CNRP) bars as self-sensing reinforcement bars for reinforced concrete (RC) members. The CNRP bars were embedded in concrete in place of conventional steel rebars and instrumented to measure electrical resistance changes in response to mechanical deformation. Sensing performance was evaluated using three-point bending tests. The results show that the CNRP bars track the flexural response and damage progression, exhibiting a decrease in electrical resistance prior to cracking, followed by a pronounced increase after crack initiation, consistent with crack propagation. These findings indicate that CNRP bars provide a fully embedded sensing approach for real-time condition assessment and support the development of self-instrumented, resilient RC infrastructure.

Speaker



Gahyeon Eom

Master student | Hanyang University

ID 515: The Influence of Environmental Factors on the Stress-Sensitivity of Self-Sensing Cementitious Composites

2:55 PM – 3:15 PM

Author(s): Khalilullah Taj, Louisiana State University; Mohammed Alnaggar, Oak Ridge National Laboratory; Yen-Fang Su, Louisiana State University

Recent investigations show that self-sensing cementitious composites (SSCC) are an affordable alternative to conventional structural health monitoring (SHM). SSCC is a multifunctional material that can detect damage, strain, and stress in the concrete infrastructure. This capability is achieved by incorporating electrically conductive fillers in the cementitious mixture. However, environmental conditions, such as changing temperatures and humidity levels, have an undesirable effect on the underlying self-sensing mechanism. To achieve reliable load monitoring, these effects need to be decoupled from the self-sensing mechanism. Therefore, this study aims to investigate the effects of temperature and humidity on the electrical and piezoresistive properties of SSCC. While monitoring the electrical resistance, temperature sweeps between 20 °C and 80 °C, and drying sweeps from surface saturated to oven dry conditions will be performed. The internal temperature and relative humidity will be detected by thermocouples and hygrometers embedded in the SSCC specimens.

Geometry, more specifically, the dimensionality of the conductive fillers, can affect the electrical and piezoresistive properties of the SSCC. To this end, the temperature and drying sweeps will be performed on SSCC specimens incorporating 0D, 1D, and 2D conductive fillers (e.g., carbon black, milled carbon fiber, and pristine graphene, respectively) at varying contents. Finally, a numerical relationship between the humidity effects, electrical resistance, and the self-sensing sensitivity index "stress sensitivity" will be formed. From the outcome of this study, a better understanding of the influence of environmental conditions on the self-sensing mechanism will be gained.

Speaker



Khalilullah Taj

Mr. | Louisiana State University

ID 565: Durability Performance of Portland Limestone Cement (Type IL) under Sequential Carbonation and Alkali-Silica Reaction

3:15 PM – 3:35 PM

Author(s): Awetehagn Gebremariam, Colorado State University; Mahmoud Shakouri, Boise State University

Carbonation, alkali-silica reaction (ASR), and chloride ingress are among the most critical degradation mechanisms affecting the durability and service life of reinforced concrete infrastructure. In actual service environments, these processes rarely occur in isolation; rather, they often develop sequentially or interactively, leading to complex chemical and physical changes in the cementitious matrix. Such interactions are particularly relevant for Portland limestone cement (PLC, Type IL), which is increasingly adopted to reduce the carbon footprint of concrete construction. This study investigates the coupled and sequential effects of carbonation and ASR on chloride transport and binding behavior in Type IL cement systems, intending to elucidate governing mechanisms and inform durability-driven material design.

Mortar mixtures with water-to-cement ratios of 0.4 and 0.5 were cast into prism molds (3.5" × 2.75" × 19"), compacted, and cured in lime-saturated water at 23 ± 2 °C until exposure. The prisms were then sectioned into six cubic specimens using a masonry saw and subsequently subjected to individual and sequential alkali-silica reaction (ASR) and carbonation exposures. Five exposure conditions were evaluated: control (no exposure), ASR-only, carbonation-only, ASR followed by carbonation (ASR+C), and carbonation followed by ASR (C+ASR). ASR exposure was conducted in accordance with ASTM C1260 using a 1 M NaOH solution at 80 °C, while carbonation exposure was carried out for 90–120 days under 10% CO₂, 65 ± 5% relative humidity, and 23 °C. Post-exposure characterization included ultrasonic pulse velocity (ASTM C597), porosity (ASTM C642), sorptivity, pore solution pH and electrical resistivity using a pore expression method, and thermogravimetric analysis to assess phase changes. Chloride binding capacity was evaluated using chunk specimens exposed to NaCl solutions of varying concentrations (0.3, 1, and 2 mol L⁻¹), with bound chloride quantified by potentiometric titration. Chloride transport properties were assessed following ASTM C1556, with chloride profiles obtained through precision milling using a 3-axis Lagun Republic milling machine and acid-soluble chloride analysis, and apparent diffusion coefficients determined by fitting Fick's second law.

Results indicate that exposure sequence plays a critical role in controlling chloride transport behavior. Specimens subjected to ASR before carbonation (ASR+C) exhibited the most pronounced reduction in chloride binding capacity and the highest apparent diffusion coefficients, attributed to ASR-induced microcracking combined with carbonation-driven decalcification and binding phase degradation. In contrast, specimens carbonated before ASR (C+ASR) retained comparatively higher binding capacity and lower diffusion coefficients, suggesting that early carbonation partially suppressed ASR development and limited microstructural damage. These findings highlight the importance of considering sequential degradation mechanisms when evaluating the long-term durability of PLC-based concretes and provide mechanistic insights relevant to service-life prediction and resilient infrastructure design.

Speaker



Awetehagn Gebremariam

Mr. | Colorado State University

MS 012: Objective Resilience: Advancing Multi-Hazard Physical- Socio-Economic Community Resilience using Physics- and AI-based Modeling and Digital Technologies

2:15 PM – 3:35 PM | Location: UMC 382-384-386

Chair(s): Omar Nofal; Milad Roohi; Yousef Darestani; Lisa Wang

Moderators



Omar Nofal

Assistant Professor | Florida International University

ID 855: Field-Calibrated Reliability Framework for Performance-Based Tornado Design of Wood-Framed Residential Structures

2:15 PM – 2:35 PM

Author(s): Pramodit Adhikari, University of Nebraska-Lincoln; Milad Roohi, University of Nebraska-Lincoln

Traditional wind design relies on prescriptive codes (ASCE 7) derived from steady-state wind tunnel testing and historical meteorological data. However, the unique kinematics of tornadic vortices and the complexity of debris-induced damage often led to significant discrepancies between code-predicted performance and observed field damage. This research introduces an inverse-problem-driven modeling framework that reimagines wind design by working backward from desired performance outcomes to underlying design requirements. By fusing Bayesian-updated fragility inference with spatial reliability analysis, the framework enables a shift from prescriptive code compliance to truly Performance-Based Wind Design (PBWD), unlocking data-informed, risk-consistent, and site-specific design decisions. This is achieved by casting the structure as a set of failure-critical components and pathways, parameterized with updated capacity information (e.g., roof-to-wall connections, roof system types), and working backward to isolate discrepancies between inferred performance and model assumptions. This is demonstrated by utilizing a multi-level probabilistic workflow that maps field observations back to structural parameters through the Bayesian framework. This requires recalibrating the prior probability distribution of structural capacities and demand parameters to maintain consistency with the revised fragility models.

This research also analyzes proximity effects observed in the recent tornado outbreak to propose a “spatial modification factor” that accounts for failures in dense community clusters. The current ASCE 7-22 load factors and field-calibrated performance for certain residential archetypes are investigated to assess the consistency of the code-intended safety margins across these archetypes. The research bridges the gap between empirical observations and codified values, providing a data-driven path towards community-level tornado resilience.

Speaker



Pramodit Adhikari

Graduate Research Assistant | University of Nebraska - Lincoln

ID 895: Probabilistic Hurricane Damage and Loss Modeling for Residential Structures under Future Climate Conditions

2:35 PM – 2:55 PM

Author(s): Xukai Zhang, Massachusetts Institute of Technology; Samira Garshasbi, Massachusetts Institute of Technology; Hessam AzariJafari, Massachusetts Institute of Technology; Randolph Kirchain, Massachusetts Institute of Technology

Hurricanes cause substantial damage to single-family residential structures, resulting in significant economic losses and posing challenges for risk-informed decision-making. Accurate prediction of hurricane-induced structural damage and associated financial losses is therefore critical, particularly in the context of evolving construction practices and intensifying climate hazards. Damage and loss predictions can also influence decision-makers' choices regarding structural materials, including wood, masonry, and concrete.

FEMA's HAZUS model is widely used to estimate damage probabilities and economic losses for residential buildings based on numerical simulations and empirical relationships. However, the masonry fragility and loss curves implemented in HAZUS rely on outdated assumptions related to building codes, construction practices, and insurance cost structures, which may no longer reflect current conditions. Despite these limitations, HAZUS outputs continue to inform material selection, mitigation strategies, and resilience planning.

This study aims to improve hurricane-induced damage and loss predictions for masonry structures under changing climate conditions. The proposed framework incorporates (1) future climate scenarios that differ from historical hazard characteristics, (2) updated structural performance representations of loss curves reflecting current construction practices and material strengths, and (3) revised loss estimates based on contemporary cost data collected from construction industries. By reconciling simulation-based fragility and loss curves with observed damage outcomes, the proposed approach refines financial loss estimates for masonry structures and enhances their applicability under modern building codes and increasing extreme weather intensity.

In addition, this study accounts for local building characteristics and spatial heterogeneity, explicitly modeling uncertainties in building attributes and loss functions rather than relying on deterministic estimates. This probabilistic framework enables more realistic loss assessments at the community scale, supporting urban planning and pre-disaster resource allocation. The results provide improved loss predictions that can better support engineers, insurers, and policymakers in resilience planning and structural material selection.

Speaker



Xukai Zhang

Postdoctoral Associate | Massachusetts Institute of Technology

ID 218: A Scalable Socio-Physical Framework for Community-Level Post-Hazard Functionality Assessment

2:55 PM – 3:15 PM

Author(s): Omar Nofal, Florida International University

Assessing post-hazard functionality is essential for understanding how communities transition from immediate disruption to long-term recovery. Conventional vulnerability- and loss-based approaches primarily quantify physical damage and economic losses but do not adequately capture the cascading interdependencies among buildings, infrastructure networks, households, and regional economies, nor the heterogeneous impacts across population groups. This research presents a scalable, high-resolution socio-physical framework for quantifying post-hazard functionality at the building, household, and community scales. The methodology integrates fragility-based building functionality models with utility and transportation network performance, household-level social vulnerability and population allocation models, and a dynamic computable general equilibrium (CGE) model to link physical disruption with population displacement, service accessibility, labor availability, and regional economic activity. The framework is demonstrated for Lumberton, North Carolina, following Hurricane Matthew (2016), where extreme riverine flooding caused widespread building damage, prolonged power and water outages, and extensive road closures. Results show that functionality losses were driven not only by structural damage but also by compounded infrastructure outages and accessibility constraints. Socially vulnerable households, particularly low-income renters, experienced disproportionately higher probabilities of multiple concurrent disruptions. When propagated into the CGE model, building functionality losses translated into a 16% reduction in local capital stock, with measurable declines in domestic supply, employment, household income, and population out-migration, as well as secondary impacts in surrounding regions. The proposed framework advances community resilience assessment by enabling high-fidelity quantification of cascading socio-physical impacts and equity-sensitive outcomes, providing actionable metrics for resilience-informed planning, infrastructure investment prioritization, and recovery policy design.

Speaker



Omar Nofal

Assistant Professor | Florida International University

MS 013: Advances in Digital Twins for Civil Infrastructure

2:15 PM – 3:35 PM | Location: HUMN 1B80

Chair(s): Adriana Trias Blanco; Maurizio Morgese; Amirali Najafi

Moderators



Adriana Trias Blanco

Assistant Professor | Rowan University

ID 582: Developing a Multimodal Bridge Digital Twin Model for Predicting Deterioration and Structural Response Using a Video-Language Model.

2:15 PM – 2:35 PM

Author(s): Prashank Singh Yadav, Texas A&M University; Ali MohebiAlidash, Texas A&M University; Amirali Najafi, Texas A&M University; Stefan Hurlbaeus, Texas A&M University

Bridges are currently required to go through schedule-based inspection every two years according to National Bridge Inspection Standards (NBIS), but due to the lack of resources this may lead to in-actions for the bridges which require urgent attention. Inherently, due to these in-actions it faces potential risk to safety hazards, catastrophic failure, cost and time. Key challenges required to be addressed involve limited funding, lack of skilled professionals, inaccessibility to bridges and traffic delays due to bridge down-time. Our objective is to develop an accurate predictive bridge deterioration and structural response platform so that there is a transition from schedule-based to condition-based inspection. As a result inspection frequency is dependent on degree of deterioration. The developed platform also forecasts the deteriorating pattern which includes corrosion, crack propagation, etc., and corresponding structural response dependent on different environmental factors and loading scenarios. We propose a Predictive Bridge Deterioration Digital Twin Model (PBDDTM) which leverages the capabilities of Multi-Modal Language Model. Initial stage involves developing an interface between the physics-based model which involves multiple sensors data and visual model developed by surface reconstruction using a point-cloud from drone footage. In the next stage Nvidia Omniverse environment is used to generate diverse and large synthetic data representing different experimental scenarios which include rare and dangerous events. Further comprehensive real and synthetic data reflecting both routine operations and edge cases is curated and annotated for AI training. Finally annotated images and sensor reading are used for training Video Language Model (VLM) to detect anomalies and recognize patterns. The developed trained VLM platform will forecast the progress of deterioration patterns and corresponding structural response representing different environmental factors, unforeseen and loading scenarios. This paper demonstrates accurate predictive capabilities of developed VLM based Deteriorating Digital Twin Model which assists decision makers in Structural Health Monitoring (SHM) and distributes resources where it is required must and helps in acting responsibly.

Keywords: Digital Twin, Video Language Model, Predictive Bridge Deterioration.

Speaker



Prashank Yadav

Mr | Texas A&M University

ID 621: Agent-based modeling approach to Transportation Networks during Flooding Events

2:35 PM – 2:55 PM

Author(s): Scott Northedge, Texas A&M

In large urban areas, it is essential that the traffic network run efficiently to service communities. When these networks fail either due to traffic accidents or environmental hazards, it can affect communities leading to economic loss or loss of life. A significant portion of urban areas are located in coastal regions, which are likely to experience environmental hazards such as flooding or hurricanes. During these events, different communities are affected in different ways depending on the type of weather event and the connectivity of the city, particularly if segments become closed. Improving the understanding between infrastructure, communities and hazardous events will help local and state governments better respond to these events. Each component can be independently modeled using physics informed infrastructure models, inundation bluespot models, and community group cognitive models, all of which can be combined in an agent-based modeling approach.

To understand the transportation network, a state space modeling approach is taken using the cell transition model (CTM). By using a state space model approach combined with macroscopic traffic laws, a lightweight but accurate model can predict the flow of traffic. This state space formulation allows planners to understand how complex networks interact with communities and hazardous events.

Hazardous events can significantly affect road segment conditions, leading to damage or closure, reducing the connectivity of the transportation network. The state space model is able to simulate how these hazardous events affect the infrastructure model over time. This research prioritizes flooding events during high intensity rain events, however the concept can be applied to different weather events. Flooding is a common but sudden coastal hazard that can rapidly isolate communities without timely action. This flood modeling utilizes a bluespot model to understand where water pools across the surface. The model utilizes weather information to determine which areas receive the most precipitation combined with geographic information to identify where and when water will pool.

Hazardous weather events have increased in frequency due to the effects of climate change, their local and state governments need an accurate tool to improve evacuation planning. During hazardous events, it can be difficult to simulate individual actors due to irrational decisions, lack of trust in authorities, or poor communication. To improve both communication and trust between these groups, a more accurate model must be developed using existing agent-based modeling to reduce the loss of life and economic impacts.

Speaker



Scott Northedge

PhD Candidate | Texas A&M

ID 676: SCADA-Driven Mooring Load Estimation for Floating Platforms Using Recursive Bayesian Estimation

2:55 PM – 3:15 PM

Author(s): Ibrahim Engin Taze, UNIVERSITY OF NEW HAMPSHIRE; Md Armanul Hoda, UNIVERSITY OF NEW HAMPSHIRE; Yashar Eftekhari Azam, UNIVERSITY OF NEW HAMPSHIRE

Digital twins (DTs) of floating structures show strong potential for structural health monitoring (SHM), yet most existing implementations rely on dense sensing or assumed environmental loads, which limits field deployment. This study presents the third phase of an estimation-first digital twinning framework that integrates operational SCADA data with sparse structural response measurements to enable practical, output-only monitoring of floating systems. Building on prior experimental work, this phase focuses on full-scale operational data from three floating systems: a floating offshore wind turbine, a floating bridge, and a floating residential structure. A physics-based reduced-order model (ROM) is coupled with recursive Bayesian estimators to reconstruct unmeasured environmental and anchoring loads under realistic sensing constraints. Both established Kalman-based approaches (Augmented and Dual Kalman Filters, AKF and DKF) and recently developed minimum-variance unbiased (MVU) estimators (the Universal Filter and Universal Smoother, UF and US) are implemented and compared. The UF and US, impose no stochastic or structural assumptions on unknown inputs and have seen very limited experimental or field-scale validation to date. By applying these estimators to operational SCADA and response data, the study contrasts Kalman-based and MVU formulations in terms of load reconstruction capability, uncertainty behavior, and sensitivity to sensing limitations. Multiple sensor configurations are evaluated to identify the minimum instrumentation required to maintain reliable estimation and DT fidelity.

Speaker



Ibrahim Engin Taze

PhD Student | University of New Hampshire

ID 1036: Development of a BIM-based digital twin for disaster performance of road facility networks

3:15 PM – 3:35 PM

Author(s): Hyojoon An, Inha university; Jong-Han Lee, Inha university

This study presents an advanced digital twin framework for managing the seismic performance of road facility networks by integrating Geographic Information Systems (GIS), Building Information Modeling (BIM), and structural analysis tools. Road networks, composed of interconnected roads and bridges, play a critical role in urban resilience. However, conventional management approaches often assess facilities individually, lack automated model generation, and provide only one-way data exchange between BIM and analysis platforms. To address these limitations, the proposed framework establishes a bidirectional, network-level digital twin that supports automated modeling, seismic simulation, and performance-based updating. The framework consists of five main steps: data collection, automated network BIM generation, data transformation for analysis integration, seismic performance assessment, and BIM updating for archiving and visualization. GIS data are used to automatically generate terrain, road, and bridge objects while preserving topology and attribute information. Object-specific Levels of Development (LoDs) guide the transformation of BIM data into finite element models, ensuring consistency between geometric detail and analytical requirements. Seismic fragility analysis evaluates the structural performance of bridges, while functional performance at both individual and network levels is quantified using traffic capacity and travel time metrics. The results are then embedded back into the BIM environment, enabling time-dependent visualization and multi-event management within a digital twin framework. A case study conducted in Gyeongju, South Korea—an area affected by a Mw 5.8 earthquake—demonstrates the feasibility and applicability of the system. The automated workflow efficiently generated a large-scale network BIM and quantified both structural damage probabilities and network-level performance degradation and recovery. By integrating modeling, analysis, and visualization within a unified digital twin, the proposed framework supports data-driven decision-making, long-term resilience assessment, and sustainable infrastructure management.

Speaker



Hyo Joon An

Postdoctoral researcher | Inha university

MS 093: Advances in geomechanics and geophysics for sub-surface technology and natural hazard

2:15 PM – 3:35 PM | Location: VAC 1B20

Chair(s): Ghassan Shahin; John Rudnicki; Giuseppe Buscarnera

Moderators



Giuseppe Buscarnera

Professor | Northwestern University

ID 82: A Surface Poroplasticity Model for Water-Induced Weakening and Instability in Carbonate Rocks

2:15 PM – 2:35 PM

Author(s): Hooman Dadras, Civil Engineering Department, University of Colorado Boulder; Yida Zhang, Civil Engineering Department, University of Colorado Boulder

In carbonate reservoirs, fluid–rock interactions can reduce strength and stiffness (“water weakening”), increase compressibility, and alter permeability—effects that directly impact reservoir productivity and geomechanical stability [Dautriat et al., 2016; Liteanu et al., 2013]. Chalk reservoirs in particular, such as the Cretaceous chalks of the North Sea, combine high intergranular porosity ($\approx 35\text{--}45\%$) with low permeability, yielding large hydrocarbon storage capacity but challenging production [Delage et al., 1996; Liteanu et al., 2013]. A well-documented example is the Ekofisk field, where reservoir compaction and seabed subsidence were observed during production and persisted despite repressurization efforts. Moreover, water flooding was associated with additional subsidence [Collin et al., 2002; Delage et al., 1996; Heggheim et al., 2005; Homand and Shao, 2000; Liteanu et al., 2013; Xie and Shao, 2006].

Despite extensive laboratory evidence that aqueous and polar fluids (e.g., water, glycol, methanol) can substantially alter the strength of dry chalk, the controlling mechanism remains debated. Proposed explanations include capillary effects, chemical dissolution, electrical double-layer forces, and adsorption pressure [Heggheim et al., 2005; Madland et al., 2006; Risnes et al., 2003; Risnes et al., 2005]. Recently, we showed that hydration forces plays a dominant role in the reduced fracture toughness of single calcite crystals [Dadras et al., 2025]. These findings indicate that short-range fluid–surface interactions can significantly modify crack behavior, with potential implications for macroscopic damage evolution in carbonates.

Building on these observations, we develop a thermodynamically consistent surface poroplasticity model in which chalk surface energy depends explicitly on fluid chemistry (e.g., polarity, salinity). The model is formulated to capture coupled plasticity and damage under different saturating fluids, and is extended with a modified flow rule to reproduce dilation–compaction transitions typical of porous rocks. To connect microscale fluid effects to macroscale localization, we employ a continuum bifurcation analysis in the spirit of Rudnicki and Rice [Issen and Rudnicki, 2000; Rudnicki and Rice, 1975] to predict the onset and the orientation of localized bands as stress and fluid chemistry vary. The results provide a mechanistic pathway linking fluid chemistry to instability and reservoir-scale weakening, offering an explanation for the pronounced water sensitivity observed in experiments and providing a predictive tool for assessing compaction risk during fluid injection and extraction in chalk reservoirs.

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Speaker



Hooman Dadras

Graduate Research Assistant | University of Colorado Boulder

ID 658: Nascent In-Situ X-ray Probes and Digital Twins for Rock Mechanics

2:35 PM – 2:55 PM

Author(s): Ryan Hurley, Johns Hopkins University; Subham Bose, Johns Hopkins University; Ahmed Al Busaidi, Johns Hopkins University

A key pursuit in sandstone mechanics is an understanding of how crystallographic texture, structure, and initial stresses influence mechanical properties and phenomena such as fracture. This question has implications for hydrocarbon extraction and CO₂ sequestration in sandstone reservoirs. This question also links to grand challenges identified in recent Department of Energy's (DOE) Roundtable Reports and is the focus of many research efforts in the DOE Geosciences basic research portfolio.

Nascent X-ray probes and digital twins, or computational replicas of physical specimens, offer an avenue to answering this question. Nascent X-ray tomography (XRT) and high energy diffraction microscopy (HEDM) measurements can be used to provide the texture, structure, and initial stresses in laboratory-scale specimens in exquisite detail and with spatial resolution down to a micron. When combined in-situ with mechanical testing of rock specimens, they further offer the ability to carefully construct, calibrate, and validate digital twins. Computational testing of synthetic sandstones using a validated digital twin framework is a route to testing rock specimens with varying texture, structure, and initial stresses, without the labor and cost of performing experiments.

In this work, we discuss nascent X-ray probes for examining the relationship between texture, structure, initial stress, and mechanical properties of sandstones. We will focus on XRT, far-field HEDM, and near-field HEDM measurements applied to millimeter-scale Nugget and Bentheimer sandstone specimens. Next, we discuss constructing digital twins in the finite element method (FEM) from initial XRT and HEDM datasets using commercial software, as in our recent work on granular materials and concrete. We discuss approaches for calibrating and validating the digital twin models. Finally, we provide a proof-of-concept demonstration of construction of a digital twin for Nugget sandstone specimens imaged using XRT and HEDM.

This contribution demonstrates a digital twin pipeline that will provide a powerful tool for addressing the competing roles of texture, structure, and initial stresses on mechanical properties and fracture in sandstone.

Speaker



Ryan Hurley

Associate Profesor | Johns Hopkins University

ID 887: A Kinematics-Driven Framework for Progressive Failure Assessment in Slopes

2:55 PM – 3:15 PM

Author(s): Plenyo Nahen Gonzaga Araujo, Northwestern University; Giuseppe Buscarnera, Northwestern University

Progressive failure is widely recognized as a governing mechanism in the evolution of landslides, particularly in slopes of brittle geomaterials that are subjected to time-dependent environmental forcing. Traditional slope-stability methods based on perfect plasticity provide valuable indicators of global safety but are inherently limited by their reliance on strong assumptions not always fully applicable to geomaterials and the treatment of the shear resistance as uniformly mobilized along a slip surface. To overcome these constraints, this study introduces a kinematics-driven framework that assesses stability conditions in natural and engineered slopes by explicitly linking field-scale measurables (e.g., surface deformation), constitutive behavior of the slip zone material, and the progressive accumulation of shear strains along potential slip surfaces. The proposed framework builds on the premise that failure emerges from a spatially-varying shear strength mobilization. By adopting a family of admissible velocity fields and enforcing compatibility along hypothesized slip surfaces, the method captures the evolution of internal deformation while allowing mechanical parameters to mobilize progressively. This kinematic formulation is coupled with a constitutive representation able to describe strain-dependent reductions in shear resistance, thereby providing a mechanistic pathway for transitioning from stable slope deformation to impending failure. Comparisons with established slope stability methods show that the proposed approach converges to classical factors of safety in case of perfectly plastic shear zones, but diverges when progressive failure controls the response. In these cases, the kinematics-driven framework identifies localized zones of strain concentration, offering an improved interpretation of the failure path and enhanced predictive capability. Applications to synthetic slopes representative of field conditions illustrate that the method can integrate kinematic observations at the slope surface, such as InSAR-derived velocities, into a unified stability assessment that evolves through time. Overall, this work presents a generalizable and computationally accessible approach that moves beyond the assumptions of classical analyses. By embracing the mechanics of progressive failure, the framework provides a physically grounded interpretation of evolving slope stability conditions and opens opportunities for coupling observational data with predictive modeling in geotechnical hazard assessment.

Speaker



Plenyo Gonzaga Araujo

Northwestern University

ID 888: Surrogate Modeling of Surface Fault Rupture From 3D Discrete Element Simulations

3:15 PM – 3:35 PM

Author(s): Joan Atieno Onyango, 1. University of Michigan ; 2. Jomo Kenyatta University of Agriculture and Technology; Xin Wei, University of Michigan; Estéfan Garcia Fernando, University of Michigan

Surface fault rupture poses a significant hazard to critical infrastructure and life, particularly where surface or near-surface deformation accompanies fault movement during earthquakes. Predicting the extent and style of this rupture remains challenging because near-fault deformation is highly nonlinear and sensitive to the overlying soil material properties. The three-dimensional discrete element method (DEM) has emerged as a highly effective tool for simulating fault rupture in granular soils, as it explicitly tracks the motion and interaction of individual particles while capturing important phenomena such as strain localization, and rupture propagation. The challenge with DEM is its substantial computational demands, which are usually overcome with the aid of high-performance computing resources.

This study presents a physics-informed, data-driven framework that combines the rigor of 3D DEM with the efficiency of machine learning to create surrogate models capable of predicting surface fault rupture characteristics with greatly reduced computational effort. A comprehensive dataset of DEM simulations generated using the open-source LIGGGHTS software was developed to represent dip-slip faulting through layered granular media, parameterized by physically defined inputs including fault dip, depth ratio, layering, and density contrast.

The approach first derives a set of physically interpretable engineering metrics including the deformation zone width, scarp geometry and surface rupture daylighting point. Together, these metrics transform raw displacement data into compact, meaningful descriptors of the surface fault rupture. The resulting database clearly separates simulation inputs from modeled outputs enabling supervised learning without embedding arbitrary assumptions. Grouped cross-validation ensures generalization across physically distinct simulations.

The proposed framework replicates the spatial trends and behavioral transitions observed in full 3D DEM outputs yet require only a fraction of the computational resources. By combining the physical accuracy of DEM with computationally efficient surrogate representations, this framework offers a practical and scalable method for exploring the parameter space of surface fault rupture. The resulting surrogate models can be rapidly deployed to inform probabilistic hazard assessments, guide engineering design near active faults, and support the development of performance-based mitigation strategies for surface rupture hazards.

Speaker



Joan Onyango

Research Scholar | University of Michigan

Coffee Break

3:35 PM – 4:00 PM | Location: UMC - Aspen Rooms & UMC - 235

MS 010: Digital Twin and AI Innovations in Smarter Civil Infrastructure Monitoring and Management

4:00 PM – 6:00 PM | Location: HUMN 250

Chair(s): Yuguang Fu; Yasutaka Narazaki; Kareem Eltoumy; Wenjun Cao

Moderators



Yuguang Fu

Assistant Professor | Nanyang Technological University



Yasutaka Narazaki

Prof. | Zhejiang University

ID 276: Finite Element Model-Integrated Fourier Neural Operators for Output-Only Ground Motion Inference

4:00 PM – 4:20 PM

Author(s): Eunchan Oh, University of Seoul; Sunjoong Kim, University of Seoul

After earthquakes, quantitative assessment based on internal force demands is essential for evaluating structural performance. In digital twin frameworks, updated finite element models can estimate these unmeasured demands through nonlinear analysis. However, the required input ground motion is often unavailable due to the limited availability of direct seismic input measurements. Although response-based ground motion estimation has been investigated, supervised sequence-to-sequence deep learning approaches require paired ground motion–response datasets, which are difficult to construct when structure-specific ground motion labels are not available. To address this limitation, this study proposes an output-only learning framework for ground motion inference. A Fourier Neural Operator maps measured acceleration responses to input ground motion. The inferred ground motion is then applied to a nonlinear OpenSees model, and the reconstructed response is compared with the measured response through a response-consistency loss, enabling training without direct ground motion supervision. Since OpenSees is outside the automatic differentiation graph of the neural network, Discrete Adjoint Method is used to compute sensitivity of the response-consistency loss with respect to the inferred ground motion, enabling end-to-end training of proposed framework. The response loss is further weighted based on amplitude distribution to better capture non-stationary earthquake responses. In addition, statistical prior information obtained from the PEER ground motion database is incorporated as auxiliary loss terms imposed on the inferred ground motion to constrain the ill-posed inverse problem. The proposed framework was evaluated using simulation data from a reinforced concrete frame modeled in OpenSees. The inferred ground motions captured the overall temporal patterns and response-spectral characteristics of the reference ground motions over test data. Using these inferred ground motions, nonlinear FE analyses reproduced not only measured acceleration responses but also unmeasured structural responses, including peak element force demands. These results demonstrate the potential of the proposed framework for digital twin-based post-earthquake safety assessment.

Speaker



Eunchan Oh

University of Seoul

ID 469: Bridge Inspection Embodied Question Answering (BIEQA): Vision Language Model-based navigation strategy in 3D scenes for Bridge Inspection Embodied Question Answering

4:20 PM – 4:40 PM

Author(s): Yasutaka Narazaki, Zhejiang University; Mingyu Shi, Zhejiang University; Wenhao Chai, Princeton University; Robin Kim, Seoul National University

Bridges are important infrastructure, and their structural safety, durability and reliability provide important support for economic and social development. Structural inspection is a critical step of bridge condition assessment to guide the operation and maintenance of the bridge. However, the traditional manual bridge inspection is time-consuming and inefficient, motivating the automation of the bridge inspection process. Recently Large Language Models (LLMs) and Vision Language Models (VLMs) have demonstrated their potential for enabling automation of real-world tasks through autonomous agents that can process and reason about complex data, tasks and their relations. Embodied Question Answering (EQA) is one of the promising ways for autonomous bridge inspection. This research proposes a novel VLM-based navigation strategy in 3D scenes for Bridge Inspection Embodied Question Answering. By providing the question about the bridge inspection task, the VLM agent embedded in the robot perceives the environment with the memory mechanism. Based on the multi-level understanding of the scene and the historical exploration, the VLM-based agent provides action plans and decision-making strategies. According to the multimodal memory during bridge inspection missions, the agent will answer the question after exploration. The proposed approach will contribute to bridge condition assessment without manual intervention, and effectively improve the level of automation in bridge inspection.

Speaker



Yasutaka Narazaki

Prof. | Zhejiang University

ID 682: Dmg2Former: A Computationally Efficient Vision Transformer Architecture for AI-Driven Infrastructure Monitoring

4:40 PM – 5:00 PM

Author(s): Kareem Eltouny, Simpson Gumpertz & Heger Inc.; Xiao Liang, Texas A&M University

High-resolution visual inspection data offers massive opportunities for digital twin-based structural health monitoring (SHM), yet it introduces a significant bottleneck. Traditional vision-based SHM methods often fall into one of two constraints: they either sacrifice micro-level details like barely-visible cracks and material boundaries through aggressive downsampling, or they face significant latency issues by attempting to process native-resolution imagery, if it was even feasible given the available hardware. We address this tradeoff with a novel architecture that pairs vision transformers with Laplacian pyramid-based adaptive rescaling networks. This approach allows for pixel-level damage detection without the computational overhead typically associated with high-resolution transformer backbones.

Our framework utilizes two complementary rescaling networks to perform non-uniform image scaling. By prioritizing high-frequency content in regions where defects are likely, the system can aggressively compress uninformative background areas while preserving essential geometric features. These rescaled representations are then fed into a transformer-based segmentation backbone. Because the input is optimized, the transformer can generate high-fidelity inspection masks at speeds that meet near-real-time synchronization requirements. Tests on benchmark available datasets show that the use of proposed adaptive rescalers improved the pixel-level classification accuracy while maintain a relatively low computational overhead. The efficiency of the architecture makes it a viable candidate for edge computing, enabling on-site processing across large-scale infrastructure portfolios and removing the primary barrier to integrating high-resolution visual data into operational digital twin systems for civil infrastructure management.

Speaker



Kareem Eltouny

AI Researcher | Hedral Inc

ID 891: Structural identification and load estimation using fiber optic sensing and differentiable simulators

5:00 PM – 5:20 PM

Author(s): Matthew DeJong, University of California, Berkeley; James Xu, University of California, Berkeley; Jeffrey Cheng, University of California, Berkeley

Structural Health Monitoring (SHM) plays a critical role in ensuring the safety and longevity of engineering infrastructure. However, current methodologies are frequently challenged by the need to interpret extensive sensor data to identify unknown parameters, particularly in dynamic environments where external forcing functions are not directly observable. Traditional approaches, such as standard system identification and Bayesian filtering, often struggle to resolve the complex interdependence between system states, material properties, and external inputs. To address these limitations, this study investigates the use of distributed fiber optic sensing data and differentiable simulators for the estimation of inputs, parameters, and states in dynamical systems.

We propose recontextualizing the inverse problem of model updating as a Partial Differential Equation (PDE)-constrained optimization problem. By leveraging recent advancements in automatic differentiation (AD), we employ fully differentiable simulation pipelines that enable efficient gradient-based optimization for high-dimensional estimation problems. For this purpose, both the Differentiable Material Point Method (DiffMPM) and Differentiable Finite Element Method (DiffFEM) were used. MPM and FEM, coupled with AD, facilitate the inference of spatially varying elastic properties and complex loading parameters directly from dynamic strain data.

To validate the efficacy of this methodology, data from two case studies were employed. First, both the DiffMPM and DiffFEM frameworks were evaluated using data from laboratory tension tests on reinforced concrete (RC) structural elements. In the lab, fiber optic sensing and digital image correlation were used to measure distributed strain in structural elements at several load levels and damage states. The resulting data were then used as input to evaluate the ability of the differentiable simulation frameworks to infer the material properties (i.e., stiffness) and loading on the system as damage progresses. Both DiffMPM and DiffFEM were effective, although DiffFEM was found to have clear advantages. The results indicate that the proposed framework successfully provides the correct inputs, parameters, and states, even when starting from poor initial assumptions or operating with sparse data.

Second, the DiffFEM framework was employed to perform structural identification and load estimation for a real wind turbine in Oklahoma. In this case, although the approximate wind speed and direction were measured, the exact loading induced on the wind turbine tower, resulting from stochastic wind interacting with the turbine blades, is not known. Additionally, model parameters (e.g., rotational foundation stiffness) are also uncertain. In this case, DiffFEM was employed to learn the model parameters as well as the effective loading induced by the wind, demonstrating its utility for input-parameter-state estimation.

In summary, this work highlights the transformative potential of differentiable physics for SHM applications. By treating the physics simulator as a differentiable operator within a gradient-based learning loop, this approach offers a scalable, interpretable, and robust solution for determining structural health and understanding performance under previously unknown loading conditions.

Speaker



Matthew DeJong

Professor | University of California, Berkeley

ID 680: Forecasting Bridge Deck Deterioration with Trustworthy AI: A Temporal Fusion Transformer Framework for Decision Support

5:20 PM – 5:40 PM

Author(s): Rohit Battula, University of Oklahoma; Hayden Gilbert, University of Oklahoma; Arif Sadri, University of Oklahoma; Aikaterini Kyprioti, University of Oklahoma

Bridges are critical to transportation resilience, economic connectivity, and public safety, yet aging bridge networks across the United States face increasing stress from climate variability and growing traffic demands. Reliable prediction of bridge deck deterioration is essential for risk-informed maintenance planning and hazard resilience, particularly under compounding environmental and operational uncertainties. This study focuses on forecasting bridge deck condition in Oklahoma using a trustworthy, data-driven modeling framework that integrates environmental exposure, traffic patterns, and historical inspection data.

High-resolution time-series data from the Oklahoma Mesonet environmental monitoring network, the National Bridge Inventory (NBI), and state transportation systems are fused to capture the coupled temporal effects of weather, loading, and structural condition. To address the complexity and heterogeneity of these datasets, Temporal Fusion Transformers (TFTs) are employed as the primary modeling approach. TFTs enable robust learning of long- and short-term temporal dependencies while providing built-in interpretability through attention mechanisms and variable importance measures—key attributes for trustworthy AI in infrastructure applications.

Predictions of bridge deck deterioration are generated to support transparent risk assessment and prioritization under incomplete and evolving information. To translate these capabilities into practice, the project includes the development of an interactive graphical user interface (GUI) that allows stakeholders to visualize predicted degradation trajectories, explore contributing drivers, and evaluate maintenance and inspection scenarios. By combining interpretable deep learning with uncertainty-informed decision support, this work contributes to advancing trustworthy AI methods for infrastructure deterioration modeling and enhances stakeholder confidence in data-driven resilience planning.

Speaker



Aikaterini (Katerina) Kyprioti

Assistant Professor | University of Oklahoma

ID 864: FE-Based Digital Twin for Performance Assessment of Composite Bridges

5:40 PM – 6:00 PM

Author(s): Péter Grubits, Department of Structural and Geotechnical Engineering, Széchenyi István University, Győr, Hungary; Maurizio Morgese, Center for Advanced Infrastructure and Transportation, Rutgers University; Majid Movahedi Rad, Department of Structural and Geotechnical Engineering, Széchenyi István University, Győr, Hungary; Ali Maher, Center for Advanced Infrastructure and Transportation, Rutgers University

Reliable bridge evaluation can be achieved through digital twin (DT) models capable of representing nonlinear structural behavior and its evolution over the structure's service life. In recent years, the increasing availability of sensor data and advanced computational tools has created new opportunities for developing digital twins that combine physics-based modelling with data-driven techniques to support long-term infrastructure assessment. Accordingly, this study presents a finite element-based DT framework for investigating the long-term performance of steel-concrete composite bridges subjected to operational conditions. The proposed approach integrates geometrically and materially nonlinear finite element analysis with cycle-induced degradation mechanisms to accurately capture the evolving structural response under different loading scenarios. The high-fidelity numerical model incorporates detailed representations of material nonlinearity, damage accumulation, and interaction between steel and concrete components, allowing realistic simulation of progressive stiffness degradation. To ensure physical consistency, the numerical model is calibrated and validated using experimental measurements, thereby enabling reliable alignment between the physical structure and its digital counterpart. This calibration process ensures that the DT accurately represents the in-service structural state and supports continuous performance monitoring throughout the operational life of the bridge. Once validated, the DT enables the reconstruction of global displacement and stress fields, as well as potential damage mechanisms, from limited sensor information. This capability allows full-field structural behavior to be inferred from sparse measurements and supports predictive assessments under loading conditions beyond those explicitly investigated experimentally. The developed DT framework facilitates continuous performance evaluation, scenario-based forecasting, and informed decision support for bridge management and maintenance planning. Its applicability and robustness are demonstrated through a large-scale experimental case study conducted at the Bridge Evaluation and Accelerated Structural Testing Laboratory (BEAST®) at Rutgers University. The investigated structure is a simply supported four-girder steel bridge with a cast-in-place reinforced concrete deck, having overall dimensions of 50 ft in length and 27 ft in width. The results highlight the potential of FE-based digital twin technology as a powerful tool for advanced monitoring, predictive assessment, and lifecycle-oriented management of bridge infrastructure.

Speaker



Maurizio Morgese

Research Engineer | Rutgers CAIT

MS 008: Advances in AI-enabled Approaches, Robotic Inspection, and Smart Sensing for Civil Infrastructure

4:00 PM – 6:00 PM | Location: HUMN 135

Chair(s): Hadi Salehi; Rih-Teng Wu; Mohammad Reza Jahanshahi; Kenneth J Loh

Moderatorss



Hadi Salehi

Assistant Professor | Louisiana Tech University



Rih-Teng Wu

Associate Professor | National Taiwan University

ID 870: Physics-Aware Deep Learning for Full-Field Deformation Sensing: A Local–Global Benchmark of cGAN, CUT, and Vision Transformers

4:00 PM – 4:20 PM

Author(s): Shao-Chung Peng, Department of Civil Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan; Wei-Cheng Chao, Department of Civil Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan; Tung-Yen Chuang, Department of Civil Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan; Chi-Ying Lin, Department of Civil Engineering, National Yang Ming Chiao Tung University, Hsinchu, Taiwan

Structural Health Monitoring (SHM) relies on accurate deformation measurements to assess infrastructure integrity. Conventional contact sensors (e.g., strain gauges and LVDTs) provide precise but spatially sparse readings and are vulnerable to damage during testing. Non-contact photogrammetric approaches can recover full-field displacement/strain responses, yet their post-processing pipeline (calibration, orientation recovery, tracking/matching, and reconstruction) remains computationally demanding, which limits timely assessment. This study presents an end-to-end deep learning framework that predicts dense displacement and strain heatmaps directly from structural surface images, aiming to reduce reliance on repeated photogrammetric reconstruction while preserving full-field outputs.

To systematically evaluate the trade-off between sensing complexity and prediction fidelity, we compare the framework across four experimental configurations: (1) multi-view inputs predicting displacement, (2) single-view inputs predicting displacement, (3) multi-view inputs predicting strain, and (4) single-view inputs predicting strain. For all configurations, ground truth is derived from a rigorous four-camera photogrammetric workflow, where time-varying 3D coordinates are reconstructed and strain is computed using the Green–Lagrange formulation to accommodate large deformation and rigid-body motion. The resulting sparse measurements are interpolated into normalized 2D heatmaps for supervised learning. A physics-aware augmentation strategy is adopted; in particular, rotation augmentation is intentionally excluded to preserve the directional semantics of gravity- and loading-induced strain components.

We evaluate three representative architectures that differ in how they capture local detail and global consistency: (1) a conditional GAN (cGAN) enhanced with gradient-difference constraints to emphasize high-frequency crack boundaries; (2) a Contrastive Unpaired Translation (CUT) model guided by patch-level contrastive learning and augmented with a frozen, pre-trained Vision Transformer feature-consistency loss to encourage global coherence; and (3) a ViT encoder–decoder tailored for dense prediction, leveraging multi-head self-attention to capture long-range spatial dependencies and a smooth upsampling decoder to produce continuous fields without checkerboard artifacts.

Experiments on a dataset of 120 samples (with held-out evaluation) reveal a clear trade-off between local sharpness and global continuity. Convolutional approaches (e.g., cGAN) better delineate fine crack edges but are more susceptible to training instability and artifact-like textures, whereas the ViT-based framework produces smoother and more physically consistent deformation patterns, with consistently higher SSIM and lower LPIPS relative to CNN-based baselines. Overall, the study highlights Transformer-based models as a practical learning-based alternative for full-field structural response estimation and offers a controlled comparison between single-view and multi-view inputs under the same ground-truth generation and evaluation protocol.

Speaker



Shao Chung Peng

Undergraduate Student | National Yang Ming Chiao Tung University

ID 918: Target-free Displacement Measurement Using Advanced Optical Flow and Structural Geometry

4:20 PM – 4:40 PM

Author(s): Chen Wei Chang, Department of Civil Engineering, National Taiwan University; Yi Chang Chen, Department of Civil Engineering, National Taiwan University; Rih-Teng Wu, Department of Civil Engineering, National Taiwan University

Vision-based Structural Health Monitoring (SHM) offers a powerful non-contact alternative to traditional sensors, enabling dense measurements without the complexity of installing physical cables. However, conventional optical flow algorithms are highly sensitive to micro-vibrations and suffer from the issue of integration drift, where small estimation errors are accumulated over time to reduce long-term accuracy. On the other hand, emerging deep learning models are stable but often lack precision, since the convolution and pooling operations do not preserve fine details, and quantization noise is introduced during the training process. To address these issues, this study proposes a target-free dual-reference optical flow framework to estimate excitation-induced structural displacements using images. First, a geometric calibration strategy utilizes the building's inherent straight lines and physical dimensions to simultaneously perform lens distortion correction and scale conversion, establishing a consistent physical measurement space without checkerboard targets. Second, a parallel tracking architecture executes a multi-level optical flow to capture fast dynamics while utilizing a periodic reference check to maintain global stability. Crucially, an adaptive fusion mechanism is integrated directly within the tracking phase to perform instant trajectory corrections. Unlike conventional methods that rely on post-processing filters, which often accidentally remove genuine residual deformations, the proposed online approach effectively preserves the true structural response. Finally, the stabilized pixel trajectories are transformed into metric displacements through the established geometric mapping, followed by a signal smoothing step to suppress high-frequency noise. Two datasets containing micro-vibration and large-scale displacements are employed to evaluate the proposed approach. In micro-vibration scenarios, the proposed approach reduces estimation errors by 49.2% (NRMSE 1.63%) compared to baseline methods. In large-scale seismic scenarios with movements up to 200 mm, the proposed approach remains stable with an error rate of merely 1.08%. In comparison, the other two baseline methods exhibit higher error rates of 2.05% and 1.88%. This demonstrates the robustness of the proposed approach in estimating displacements of varying scales. More importantly, the proposed approach successfully distinguishes between tracking errors and displacement responses, accurately identifying a 5.56 mm permanent residual displacement that was missed by conventional approaches, demonstrating a great potential for reliable post-disaster assessments.

Speaker



Chen Wei Chang

National Taiwan University

ID 919: A Deep Reinforcement Learning-based Framework with Global Information Encoding for UAV Robotic Inspection

4:40 PM – 5:00 PM

Author(s): YungI Chang, National Taiwan University; RihTeng Wu, National Taiwan University

To ensure the safety and serviceability of civil infrastructure, regular structural health monitoring is essential. Early detection of structural damage followed by timely maintenance can extend the service life of structures and reduce the risk of accidents. In recent years, numerous studies have investigated the use of Unmanned Aerial Vehicles (UAVs) to reduce labor costs and inspection time. However, most existing UAV-based inspection approaches still rely on manual operation. In environments with limited visibility or complex surroundings, human operation errors not only reduce inspection efficiency but also increase the risk of collision. Accordingly, Robotics and Autonomous Systems (RAS) provide a more efficient alternative. Building on this concept, we propose a UAV robotic inspection system consisting of two autonomous agents: inspection and exploration. The inspection agent employs a segmentation model to extract key information about surface damage, while the exploration agent adopts Deep Reinforcement Learning (DRL) to navigate the UAV to explore and track damage instead of performing exhaustive surface coverage, thereby improving inspection efficiency. In practice, since a UAV can only observe a local region of the structure at any given time, the inspection task is a Partially Observable Markov Decision Process (POMDP) scenario, whereas conventional DRL methods usually assume the current observation to be fully representative of the environment state, leading to degraded and unstable decision-making performance. To address this issue, we develop the exploration agent based on a Deep Recurrent Q-Network (DRQN), which integrates a recurrent neural network to accumulate historical observations into a latent state representation. A grid-based offline map is further incorporated to accumulate the visitation records of different regions in the environment, which serves as auxiliary information to assist the UAV in reasoning about its relative spatial location during inspection. The DRQN then navigates the UAV based on both the offline map and the output of the segmentation model to find more damage while reducing redundant movements. In a structural surface damage simulation environment constructed based on DeepCrack dataset, the proposed approach achieves crack detection rates of 95.5% and 86.1% on the training and testing datasets, respectively, corresponding to enhancements of 19.0% and 18.9% over the baseline method. Moreover, compared with exhaustive surface scanning, the proposed approach reduces the computation by more than 50%. Overall, results have demonstrated that the proposed framework maintains a high detection rate while significantly reducing redundant exploration and inspection steps, thereby boosting the efficiency of structural surface inspection.

Speaker



YungI Chang

National Taiwan University

ID 725: Network-Level Pavement Condition Index Estimation Using Deep Learning and Image Processing of RGB-D Images

5:00 PM – 5:20 PM

Author(s): Abhishek Subedi, Purdue University; Nikkhil Sankar, Purdue University; Malleswari Kachireddy, Purdue University; Mohammad Jahanshahi, Purdue University

Accurate estimation of the Pavement Condition Index (PCI) is essential for effective roadway maintenance planning and lifecycle cost optimization. Traditional PCI assessment relies on manual visual surveys that are time-intensive, subjective, and difficult to scale across large transportation networks. Recent advances in computer vision have enabled automated detection of pavement distresses. However, most existing approaches focus narrowly on individual defect types or pixel-level segmentation, without explicitly addressing the diverse set of distresses, their severity levels, and subsequent hierarchical reasoning required to infer PCI scores. The proposed approach formulates PCI assessment as a learning problem that jointly models pavement distress localization, severity characterization, and quantification. At the perceptual level, a deep neural encoder extracts spatially rich features from roadway imagery to identify multiple distresses, including cracks, surface deterioration, and patching artifacts, across varying scales and illumination conditions. These features are then aggregated through structured representations that encode both the spatial extent and relative severity of observed distresses. Rather than treating PCI as a direct regression target, the framework leverages intermediate distress-aware representations that align more closely with engineering definitions embedded in PCI guidelines. To account for the inherent subjectivity and class imbalance present in pavement datasets, the model is trained using a combination of segmentation-aware and index-consistent loss functions, encouraging robustness to sparse but critical defects. Incorporating depth maps to the RGB data further facilitates characterization of depth-based distresses, such as rutting and depressions, which are critical for PCI estimation. The framework is evaluated on a heterogeneous pavement image dataset collected under real-world conditions, encompassing diverse surface textures, distress densities, and acquisition viewpoints. Performance is assessed at both the distress level and the PCI level using standard computer vision metrics alongside PCI-specific error and correlation measures. Experimental results demonstrate that the proposed approach significantly improves PCI estimation accuracy compared to conventional baselines. The model also generalizes well across unseen roadway segments, suggesting suitability for network-scale deployment. By linking pixel-level visual understanding with depth-aware analysis, this work advances the state of automated pavement assessment and provides a scalable pathway toward objective, repeatable, and data-driven PCI evaluation using vision-based sensing.

Speaker



Mohammad Jahanshahi

Associate Professor | Purdue University

ID 273: A Multi-Modal AI Framework for Network-Level Assessment of Urban Transportation Infrastructure and Traffic Stress

5:20 PM – 5:40 PM

Author(s): Debasish Jana, Colorado State University; Ryan Alimo, Opal AI Inc.; Aniruddha Kalkar, Opal AI Inc.; Sven Malama, University of California Los Angeles; Ehsan Asali, Opal AI Inc.; Pranav Chaudhary, Opal AI Inc.; Alison Olmstead, Opal AI Inc.; Melis Fidansoy, University of California Los Angeles; Maryam Hosseini, University of California Berkeley; Sriram Narasimhan, University of California Los Angeles

Urban transportation agencies increasingly require scalable, physics-grounded, and data-driven tools to assess infrastructure condition, accessibility, and user stress across large networks. This paper presents a multi-modal artificial intelligence framework that integrates mobile LiDAR, panoramic imagery, video, aerial imagery, and graph-based network analytics to generate high-resolution, asset-level assessments of urban transportation systems. The framework was demonstrated over 156.8 miles of roadway across 7.09 square miles in Los Angeles, capturing sidewalks, crosswalks, bike lanes, curb ramps, pavement surfaces, traffic control devices, transit hubs, and roadside context.

A core contribution is the fusion of vision-language models (VLMs) for semantic interpretation with LiDAR-derived geometric measurements to extract both perceptual and engineering-relevant attributes aligned with ADA, MUTCD, NACTO, and FHWA standards. These asset-level features are embedded into a network representation, enabling computation of node and edge importance and their interaction with infrastructure condition. Building on this representation, we introduce an enhanced Level of Traffic Stress (LTS) methodology for pedestrians and bicyclists that explicitly incorporates sidewalk defects, obstructions, slopes, lighting, lane separation, and intersection characteristics, factors typically omitted in conventional LTS models.

Results demonstrate strong spatial coupling between infrastructure degradation, network importance, and elevated user stress, highlighting critical corridors where targeted investments yield disproportionate benefits. The study further illustrates how combining network importance with stress metrics enables optimization-based prioritization of capital investments under budget constraints. By unifying high-fidelity sensing, AI-based perception, and network mechanics, the proposed framework provides a scalable pathway toward equitable, data-driven transportation planning and infrastructure resilience.

Speaker



Debasish Jana

Assistant Professor | Colorado State University

ID 828: A 10-Year Journey from CrackNet for Fully Automated Pavement Condition Survey

5:40 PM – 6:00 PM

Author(s): Kelvin Wang, Montana State University (MSU); Allen Zhang, Southwest Jiaotong University

Pavement condition survey provides critical information for pavement engineering including materials, design, and management. Fully automated pavement condition survey remains a goal for many agencies. From 2015 to 2016, the research team embarked on an endeavor to develop a customized CNN network using several thousand manually labeled pavement images in 3D. This presentation discusses the initial success of the developed CrackNet which was published in 2017. Since then, nearly on annual basis the research team has continued its effort to develop new tools to address many aspects of fully automated cracking survey. This presentation reviews the progresses made in the last 10 years, and broadens the scope into other pavement surveys, such as AI-based highway-speed micro and macro-texture evaluation, and initial results of leveraging open-source AI platforms to enhance cracking segmentation."

Speaker



Kelvin Wang

Professor | Montana State University

MS 099: Computational Generalized Continua, Gradients, and Nonlocal Mechanics

4:00 PM – 6:00 PM | Location: HUMN 125

Chair(s): Richard Regueiro; Remi Dingreville; Alexander Dummer; Christian Linder; Nathan Miller; Matthias Neuner; Leong Hien Poh

Moderators



Richard Regueiro

Professor | University of Colorado Boulder

ID 488: Adaptive and kinematics-based homogenization domain selection for a micromorphic filter

4:00 PM – 4:20 PM

Author(s): Thomas Allard, University of Colorado Boulder; Nathan Miller, University of Colorado Boulder; Richard Regueiro, University of Colorado Boulder

Homogenization using a micromorphic filter has been shown to be useful for upscaling heterogeneous inelastic direct numerical simulations (DNS) within generalized continuum solid mechanics frameworks. A major advantage of the micromorphic filter over other homogenization techniques is that an entire DNS (with boundaries) may be upscaled rather than a material-point-driven representative volume. This allows one to probe the macroscale behavior of bulk, localizing, and boundary processes. A major question remains as to how to select the sizes of the regions over which homogenization is performed.

This work presents recent enhancements to a micromorphic filter aimed at systematically identifying micro-averaging and filtering domains. Several clustering strategies are investigated to group DNS points based on kinematic similarity while satisfying affine transformation consistent with micromorphic theory. In addition, an adaptive filtering strategy is introduced that refines homogenization domains in regions exhibiting large gradients in deformation and stress measures. These recent improvements are compared with previous uniform homogenization domain methods for several studies.

Speaker



Thomas Allard

Graduate Student | University of Colorado Boulder

ID 517: Strong form formulation for a high order beam theory with polynomially augmented radial basis function kinematics

4:20 PM – 4:40 PM

Author(s): Raturaj Chiddarwar, Texas A&M University; Petros Sideris, Texas A&M University

Most of the beam theories are based on the assumption that the cross-section behaves as a rigid body when subjected to arbitrary loading. In particular, the Euler–Bernoulli beam theory assumes plane cross-sections remain plane and perpendicular to the deformed beam axis and thus ignores transverse shear deformation. Although Timoshenko beam theory relaxes the orthogonality assumption to account for the shear deformation, it requires empirical or semi-empirical shear correction factors to the stiffness to account for the nonuniform shear stress distribution. These simplifications hinder accurate representation of the triaxial stress and strain profiles in beams subjected to combined axial-flexural-shear-torsional loading. To address these limitations, a high-order beam theory with polynomially augmented radial basis function (PA-RBF) kinematics is introduced. This study derives a variationally-consistent strong form of equilibrium by additively decoupling the cross-section kinematics into the lower order (Navier's) plane section hypothesis vs. higher order kinematics expressed via PA-RBFs. It proposes a computational beam element formulation that explicitly solves the strong form of equilibrium for both the low and high order fields by expressing the generalized stress resultants and the generalized displacements via global polynomial interpolants over the beam length. The proposed formulation employs displacements at strategically selected locations (Gauss–Lobatto points) as the governing variables. These locations act as interpolation (and integration) points for expressing generalized displacements and stress resultants through global polynomial interpolants along the beam axis, enabling a numerically stable and variationally consistent solution to the strong form of equilibrium. The formulation is further extended to handle inelastic constitutive relations for hardening materials, combining $(M-1)$ -order polynomial interpolants with PA-RBF kinematics for cross-sectional deformation. Numerical examples involving beams with rectangular and non-rectangular cross-sections were used to test the formulation's capability to accurately reproduce complex deformation and stress fields. The results show excellent agreement with ABAQUS FEA, confirming the robustness and accuracy of the proposed formulation for elastic and inelastic analyses.

Speaker



Raturaj Uday Chiddarwar

Ph.D. Candidate | Texas A&M University

ID 609: Localizing gradient-enhanced damage-plasticity for quasi-brittle materials with application to concrete

4:40 PM – 5:00 PM

Author(s): Alexander Dummer, Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, United States; Konstantin Basche, Department of Basic Sciences in Engineering Sciences, University of Innsbruck, Austria; Paul Hofer, Department of Basic Sciences in Engineering Sciences, University of Innsbruck, Austria; Peter Gamnitzer, Department of Basic Sciences in Engineering Sciences, University of Innsbruck, Austria; Günter Hofstetter, Department of Basic Sciences in Engineering Sciences, University of Innsbruck, Austria; Thomas Mader, Department of Landscape, Water and Infrastructure, Institute of Structural Engineering, BOKU University, Austria; Matthias Neuner, Department of Landscape, Water and Infrastructure, Institute of Structural Engineering, BOKU University, Austria

Modeling failure in quasi-brittle materials like concrete requires regularization techniques to ensure mesh objectivity. While implicit gradient-enhanced continuum models are widely established, conventional formulations with a constant internal length scale suffer from a pathological broadening of the damage zone during softening. To address this well-known shortcoming, numerous approaches have been proposed. In general, two possible modifications of the screened Poisson equation exist: one could either tune the source term or formulate an evolving nonlocal interaction parameter. From a physical point of view, a decreasing interaction parameter with increasing material damage seems to match the idea of coalescence of microcracks in a finite sized process zone to a single macroscopic crack. Following this, the localizing gradient damage approach, originally developed by Poh and Sun in 2017 for pure damage models, is a promising candidate for improving damage-plasticity models. However, as demonstrated by the authors at FraMCoS XII 2025 in Vienna, the straightforward extension of coupled damage-plasticity models to the localizing gradient approach yields both unrealistic S-shaped softening behavior in 1D tension and wrong structural predictions. In this contribution, we present a consistent framework for a novel improved localizing gradient-enhanced damage-plasticity (iLGCDP) model departing from the generalized micromorphic continuum approach introduced by Forest. The key innovation is the introduction of an improved damage formulation incorporating an evolving softening modulus that depends on the damage variable. This modification effectively rectifies the deficiencies of ad-hoc extensions and allows for precise control of post-peak ductility. The performance of the proposed model is evaluated through a comprehensive numerical study, including popular benchmark examples for concrete failure. The results demonstrate that the iLGCDP model successfully mitigates spurious damage broadening, predicting sharp, localized crack patterns while accurately capturing the load-bearing capacity and structural post-peak response compared to conventional approaches.

Speaker



Alexander Dummer

Dr. | University of Colorado Boulder

ID 668: A generalized continuum based elastoplastic phase field model for fracture in concrete

5:00 PM – 5:20 PM

Author(s): Sina Abrari Vajari, Stanford University; Christian Linder, Stanford University

Concrete's heterogeneous microstructure results in a complex quasi-brittle response and intricate mixed-mode fracture patterns under real-world loading. While the phase field approach is well-established for implicitly tracking crack propagation, purely elastic models often struggle to capture the full scope of concrete failure. Building on previous work, we present a thermodynamically consistent elastoplastic phase field formulation that accounts for the pressure-dependent strength of concrete. This model is developed within a generalized continuum framework to incorporate microstructural effects, naturally capture material size effects, and ensure numerical stability. By utilizing an internal length scale to characterize the fracture process zone, the model accurately reflects the material's internal microstructure. Validation against experimental data demonstrates the model's superior performance in predicting mixed-mode I-II and I-III failures.

Speaker



Christian Linder

Professor | Stanford University

ID 494: Development, implementation, and response of higher-order elasto-plastic material models of geo-materials

5:20 PM – 5:40 PM

Author(s): Nathan Miller, Center for National Security Initiatives: University of Colorado Boulder; Thomas Allard, Advanced Engineering Analysis: Los Alamos National Laboratory; Richard Regueiro, Civil, Environmental, and Architectural Engineering: University of Colorado Boulder

Geo-materials have historically been difficult to simulate due to their inherent length scales driven by the material heterogeneity. These length scales can be observed as changes in material properties as the size of the constituent changes which can manifest in the linear response (e.g., effective property changes in concrete for different aggregate sizes) as well as in the non-linear behavior (e.g., shear band size). The lack of a fundamental length scale in classical continuum has been addressed through many disparate approaches ranging from material-model level modifications to the addition of additional field variables such as are present in generalized continua. Of these approaches, the micromorphic continuum of Eringen is of particular interest due to its expressivity in capturing the behavior of microstructures subjected to external loading. This allows additional flexibility, at the expense of an increase in complexity, of representing the behaviors of heterogeneous materials. In addition to the modeling capabilities, the approach allows for localization processes to converge with mesh refinement allowing models to be used independently of a pre-defined discretization size.

We here propose a higher-order computational framework for the simulation of elasto-plastic material models applied to a polymer-bonded crystalline material. The framework allows for the simulation of finite-deformation materially nonlinear micromorphic continuum on arbitrary domains. We detail the theoretical construction of the model and its implementation into the Tardigrade computational framework. Simulations of compression cylinders and Brazil disks are performed and the results are compared to a similar classical continuum model demonstrating the effect of the additional micro-deformation field. Further advances on the framework are also discussed including the development of material models which attempt to circumvent the material parameter issue through the construction of strain-energy potentials derived from simplified representations of the microstructure with a view towards the incorporation of stochastic effects in future work.

Speaker



Richard Regueiro

Professor | University of Colorado Boulder

ID 449: Time Dependent Deformations in Concrete: Models over Multiple Length Scales

5:40 PM – 6:00 PM

Author(s): Biswajit Pal, CBRI, Roorkee, India; Ananth Ramaswamy, IISc Bangalore, India

Prediction of time-dependent deformation such as shrinkage and creep are of utmost interest in terms of long-term serviceability of a concrete structure. The existing formulations for creep and shrinkage modelling in concrete are empirical in nature, that have been developed based on a particular set of measured data. Further, owing to highly heterogeneous nature of concrete, existing macroscopic prediction models lack in terms of its general applicability. In this study at first, a coupled hygro-thermo-mechanical formulation is used to model the physics associated with creep and shrinkage in concrete structures in a homogenized macro-scale framework. Uncertainty tools based on a probabilistic framework are used to model the possible variations in the input variables in the hygro-thermo-mechanical formulation. A global response sensitivity analysis is adopted to identify the parameters having maximum impact on the output responses. Uncertainties in the selected set of important variables are reduced using Bayesian inference and short-time measured responses. For validating efficiency of the uncertainty reduction technique, the predictions of creep and shrinkage in concrete are compared with a few experiments from the North-Western University (NU) data base. The uncertainty reduction technique is then used to predict the long-time prestress losses in post-tensioned concrete beams and slabs cast in the laboratory. As an extension to this study, a multi-scale description is used to simulate the shrinkage and creep of concrete where the heterogeneity and associated physical-chemical processes are modelled in a mathematical framework. A hierarchical homogenisation technique is used to link across different scales. Model predicated shrinkage and creep are then validated with the corresponding experimental data. Model prediction is also compared with few national codes and popular macroscopic models to highlight the associated gaps in these models that can be overcome with the present developed multi-scale approach.

Speaker



Ananth Ramaswamy

IISc Bangalore

MS 025: AI and Machine Learning for Risk, Uncertainty, and Resilience Assessment of Structural and Infrastructure Systems

4:00 PM – 6:00 PM | Location: HUMN 1B50

Chair(s): Milad Roohi; Mohsen Zaker Esteghamati; Doeun Choe; John van de Lindt

Moderators



Do-Eun Choe

Assistant Professor | New Mexico State University

ID 577: Artificial Intelligence for improved surrogate modeling and class fragility generation of structures with correlated loads

4:00 PM – 4:20 PM

Author(s): Sushreyo Misra, Lehigh University; Paolo Bocchini, Lehigh University

Extreme events such as earthquakes and hurricanes cause widespread damage and disruption to infrastructure assets such as buildings and bridges. For large-scale structures such as tall buildings and long span bridges, these hazard events impart uneven load fluctuations at different structure locations, resulting in complex load-structure interactions. Accurate regional risk and resilience assessment of these structures requires developing portfolio level (or “class”) fragility models, which in turn requires establishing functional relationships connecting features describing the load to features defining the response, also known as the engineering demand parameter (EDP). The computational demands of running a sufficiently large number of numerical simulations to obtain these functional relationships can be largely mitigated by AI-based surrogate models. Our recent paper (Misra and Bocchini, 2026) introduced a novel physics-informed neural network architecture that guides the selection of load intensity features, commonly called “Intensity Measures” or “IMs”, and drives the creation of these surrogates. Further, our preliminary results suggest that these latent features of the excitation history, referred to herein as “meta-IMs”, enable significantly improved response and damage predictions even with relatively simple model architectures such as feedforward neural networks. This novel dual-network architecture, called “MetalMNet”, is designed to mimic the traditional engineering approach to dynamic time history analysis, by processing the full load time history through a feature extractor (v_1) and passing the structural features separately to a surrogate response predictor (v_2).

In the present study, we upgrade the preliminary MetalMNet architecture in the following ways.

1. Use advanced model architectures as Convolutional Neural Networks (CNNs) for meta-IM extraction and automate the pipeline for any hazard type and length.
2. Generalize the MetalMNet architecture to handle multi-channel inputs, where channels physically represent multiple loading histories at various structural locations.

The upgraded MetalMNet architecture is subsequently tested on two problems, a tall water tank with wind fluctuations varying along the height, and long-span bridges with variable multi-support seismic excitation. For each of the case study problems, the meta-IMs generated by MetalMNet are inspected further to extract contextual information on the loading history and structural features, thereby going beyond traditional ‘black-box’ approaches and embracing the scientific community’s push towards explainable AI models.

Cited Reference

Misra, S., Bocchini, P., 2026. MetalMNet: A physics-informed neural network architecture for surrogate response and fragility modeling of structures subjected to time-varying hazard loads. *Struct. Saf.* 118, 102650.
<https://doi.org/10.1016/j.strusafe.2025.102650>

Speaker



Sushreyo Misra

Dr. | Lehigh University

ID 620: An AI-driven computational framework for quantifying cascading effects in the built environment during extreme wind events

4:20 PM – 4:40 PM

Author(s): Rohith Swaminathan, George Mason University; Sumukh Bharadvaja Shivaram, George Mason University; Catalina Gonzalez Duenas, George Mason University

High-wind events, including severe convective storms and hurricane-force winds, pose significant risks to residential infrastructure and drive rising insured losses. A critical challenge during these events is the cascading nature of damage: debris from one structure can breach the envelopes of adjacent buildings, alter their internal pressures, and trigger progressive failures that amplify community-level impacts. Existing community-scale approaches often neglect such localized interactions, while high-fidelity CFD simulations capable of resolving them remain computationally prohibitive for large domains.

To address this gap, we present a scalable, physics-informed framework that explicitly represents debris-driven cascades while embedding high-resolution built-environment features. The framework generates paired before-and-after states of the built environment by simulating envelope breach from debris impact, the transition in internal pressure, debris generation, and trajectory. These paired states are then used to train a graph-based surrogate model that efficiently captures local interactions at the community level. Buildings are represented as nodes enriched with their geometric attributes, while edges encode spatial relations, such as the separation distance between buildings, wind orientation, and shielding effects.

We demonstrate the framework using Miami-Dade County as a case study, using parcel-level built-environment data from the Bing Maps Global Building Footprints. Involving hundreds of structures, the surrogate reproduces spatial damage patterns with substantially lower computational demands than high-fidelity simulations. Beyond wind-driven debris, the framework provides a foundation for extending cascading-effect modeling to other natural hazards—such as flood-borne debris, wildfire spread, and multi-hazard interactions during convective storms—where localized dynamics drive community-scale performance.

Speaker



Catalina Gonzalez Duenas

Assistant Professor | George Mason University

ID 738: Physics-Informed Foundation Models for Structural Digital Twin Updating via 4D Gaussian Splatting

4:40 PM – 5:00 PM

Author(s): Parham Bakhtiari, Utah State University; Mohsen Zaker Esteghamati, Utah State University

Structural health monitoring requires the accurate inference of internal system states, specifically stiffness degradation and damage, which are difficult to estimate solely from external visual observations. Current computer vision techniques effectively capture surface motion but lack the mechanical context of mass, force, and equilibrium required to interpret that motion structurally. Furthermore, pure data-driven deep learning models struggle to generalize to complex seismic events due to a scarcity of labeled training data. This study addresses these limitations by introducing physically informed 4D Gaussian splatting (PI-4DGS), a framework that integrates generative AI with mechanics-based simulation to identify structural properties directly from video.

The proposed method couples 3D Gaussian splatting with a differentiable material point method (DiffMPM) solver. This integration allows the model to process standard video footage not merely as a set of graphical pixels, but as a physical simulation constrained by the conservation of momentum. The implementation proceeds in three stages. The implementation follows three distinct stages. First, the Segment Anything Model 2 (SAM 2) semantically initializes the model, automatically identifying structural elements such as walls and windows to capture material heterogeneity. Second, a novel physics-informed low-rank adaptation (PI-LoRA) mechanism updates the structure's stiffness matrix over time. Unlike standard adaptation methods, PI-LoRA constrains the learning process using modal superposition principles, which forces the model to explain visual discrepancies as mechanically valid stiffness degradation rather than random noise. Finally, the system minimizes a composite virtual digital image correlation (DIC) loss function, synchronizing the generative visual simulation with the observed physical forces.

This framework was validated using the shake-table test of a 10-story mass timber building. NHERI Tallwood Project. By benchmarking against dense wired sensor arrays, the results demonstrated that PI-4DGS recovered inter-story drifts and constitutive parameters with high fidelity using only monocular video input. This research bridges the gap between computer vision and continuum mechanics. The expected outcome is a scalable, cost-effective method for autonomous structural assessment that removes the barrier of expensive instrumentation. By enabling neural digital twins to self-diagnose based on physical laws, this work provides the engineering community with a robust tool for resilient infrastructure management.

Speaker



Parham Bakhtiari

Ph.D. Student | Utah State University

ID 747: A Variable-Length Transformer for Inverse Performance-Based Design of Steel Buildings

5:00 PM – 5:20 PM

Author(s): Ali Namin, Graduate Student, Dept. of Civil and Environmental Engineering, Utah State University, Logan, UT 84322; Shiva Baddipalli, Graduate Student, Dept. of Civil and Environmental Engineering, Utah State University, Logan, UT 84322; Mohsen Zaker Esteghamati, Assistant Professor, Dept. of Civil and Environmental Engineering, Utah State University, Logan, UT 84322

Performance-based design (PBD) has transformed earthquake engineering by considering performance metrics including economic losses in structural design decisions. However, the traditional PBD workflow remains fundamentally a forward problem: engineers iteratively propose designs and evaluate their performance through computationally expensive nonlinear time history analysis (NTHA) until acceptable loss thresholds are achieved. This iterative process creates a significant computational bottleneck, limiting the practical application of PBD in early-stage design exploration. However, recent studies using physics-informed DL models have successfully mitigated the computational burden of NTHA. However, these approaches are mostly used to predict the seismic responses, and to date, there is no DL-based model for direct inverse design from seismic losses. In this research, to address the computational bottleneck of iterative PBD, a variable-length transformer is proposed to directly map probabilistic risk metrics, such as expected annual loss (EAL), to detailed structural components of steel buildings. In typical DL architecture, the same array sizes must be kept for all inputs and outputs, which is not suitable for a general purpose model that must generate floor-level designs of structural components for building with different geometry, including building height and floor plans. In this study, a dynamic masking mechanism is used to generate design parameters, such as sectional information, for structural elements of steel frame buildings with varying floor numbers (i.e., 1-19 floors). This study leverages a database of 621 steel moment-resisting frames with varying geometries and designs. The results show that the transformer model achieves promising performance, where the generated sectional properties are in close agreement with ones from detailed analysis and simulations. The proposed approach offers a breakthrough for DL-based PBD by generating rapid and automated inverse design that produces structural details from geometry and EAL targets, a task that traditional methods can only approximate through intensive simulation and analysis.

Keywords: Deep learning, Transformer neural networks, Performance-based design, generative structural design; Steel framed buildings.

Speaker



Ali Namin

Graduate student | Utah State University

ID 810: Opening the Black Box: Interpretable Surrogates for Tornado Loss Modeling

5:20 PM – 5:40 PM

Author(s): Mohamad Habibnia, Colorado State University; John van de Lindt, Colorado State University

Artificial intelligence (AI) and machine learning (ML) are increasingly used in natural hazard risk assessment to reduce computational cost and enable large-scale analyses. However, many existing AI-based vulnerability and loss models rely on black-box formulations that lack physical interpretability and provide aggregated uncertainty estimates, limiting their applicability for engineering decision-making and resilience planning. This study presents an interpretable, physics-informed approach for probabilistic tornado-induced loss estimation in one-story wood residential buildings, designed to balance model accuracy, transparency, and computational efficiency.

The proposed approach integrates a stochastic, physics-based tornado damage and loss model with interpretable parametric surrogate formulations. Tornado wind demands are calculated using ASCE 7-22 provisions with probabilistic load and resistance models, while damage initiation is governed by roof sheathing and roof-to-wall connection failures. Building-specific loss is computed by coupling spatially resolved roof damage patterns with probabilistic room layouts, replacement cost models, and Monte Carlo simulation. This layered approach enables explicit propagation of uncertainty from wind loading, structural response, and building contents to calculate total loss.

To develop an interpretable surrogate model, a representative set of loss results is required across buildings with diverse geometric and structural configurations. To efficiently explore the high-dimensional building parameter space, a dual-objective adaptive smart sampling strategy is then employed. The method balances exploration of both input variables and response variables, enabling the generation of a representative training dataset from millions of possible building configurations with a limited number of simulations. Interpretable parametric surrogate models are then fit to the resulting loss curves, and linear regression relationships are established between building attributes and surrogate parameters.

Results show that scaled spline-sigmoid and Weibull cumulative distribution function formulations accurately represent tornado loss behavior for gable- and hip-roof buildings, respectively, while maintaining mathematical transparency. The final framework enables rapid, building-specific loss estimation using simple closed-form expressions, making it suitable for large-scale risk assessment, uncertainty quantification, and resilience analysis.

Speaker



Mohamad Habibnia

PhD. Candidate | Colorado State University

ID 1008: AI-Driven Imputation of Missing Attributes in Building Inventories for Community Resilience Assessment

5:40 PM – 6:00 PM

Author(s): Saeid Ghasemi Gavabar, University of Nebraska-Lincoln; Milad Roohi, University of Nebraska-Lincoln

Reliable community-scale resilience assessment depends on the availability of comprehensive and high-quality building inventory data. Due to restrictions on accessing private and proprietary building databases, researchers increasingly rely on publicly available nationwide building inventories. However, publicly available building inventories often lack critical attributes required by computational frameworks for hazard, vulnerability, and resilience assessment. Missing information on structural type, construction era, height, and occupancy directly affects fragility assignment and vulnerability modeling, introducing substantial epistemic uncertainty into damage, loss, and resilience estimates. This study proposes a novel AI-driven imputation framework to enhance an open-source U.S. building inventory database by inferring missing attributes necessary for accurate natural-hazard resilience assessments. Machine-learning models are trained on parcels with complete records, integrating physical, spatial, and contextual predictors to learn nonlinear dependencies among building characteristics. Multiple AI and ML algorithms, including ensemble and generative models, are implemented to predict missing attributes and to generate statistically consistent realizations of community-building stocks, thereby enabling the explicit propagation of data uncertainty into downstream risk metrics. The framework is evaluated across multiple testbeds by benchmarking ML-imputed inventories against high-resolution assessor data and by assessing predictive accuracy, computational efficiency, and robustness under varying missing-data scenarios. The resulting inventories are propagated through seismic damage and resilience models to quantify how imputation quality influences cumulative repair ratios and community-level performance metrics. By embedding machine learning within a simulation architecture, this research establishes a scalable methodology for constructing computationally complete building inventories and advancing reliable resilience assessment in data-limited regions.

Speaker



Saeid Ghasemi

Graduate Research Assistant | University of Nebraska - Lincoln

MS 027: Bridging Numerical Modeling and Scientific Machine Learning for Next-Generation Computational Mechanics

4:00 PM – 6:00 PM | Location: HUMN 150

Chair(s): Somdatta Goswami; Souvik Chakraborty

Moderators



Souvik Chakraborty

Associate Professor | IIT Delhi

ID 618: Physics-Guided Machine Learning Acceleration of Force-Based Beam–Column Elements

4:00 PM – 4:20 PM

Author(s): Utkarsh Yadav, Simpson Gumpertz and Heger; Eduardo Montalto, University of Colorado Boulder

Force-based beam–column elements are widely used in nonlinear structural analysis because they enforce equilibrium exactly at the element level and capture plastic hinge localization with reduced mesh sensitivity compared to displacement-based formulations. Their application in nonlinear time-history analysis, however, is often limited by the high computational burden associated with repeated section-level constitutive updates and element-level compatibility iterations, particularly for fiber-discretized members. This work presents a hybrid physics-guided machine learning framework to accelerate force-based element evaluation while preserving its fundamental mechanical structure. Two neural surrogates are introduced. The first, a section surrogate implemented as a feed-forward fully connected neural network, replaces computationally intensive fiber-level state determination by learning the history-dependent mapping from section resultants to section deformations and tangent flexibility. The second, an element-level surrogate, provides an initial estimate of element end forces for a given trial deformation state, thereby reducing the number of internal iterations required to enforce element compatibility. Both surrogates are embedded within the classical flexibility-based element formulation, retaining statically admissible internal force interpolation and quadrature-based assembly of element flexibility; corrective Newton-Raphson iterations are maintained to ensure compatibility and robustness. Training data are generated from reference force-based beam–column analyses driven by prescribed displacement time histories using fiber-discretized sections and full element-level iteration as the high-fidelity baseline. A Python proof-of-concept is presented for steel beam–column sections to evaluate the feasibility of the proposed approach, with emphasis on reproducing force–deformation hysteresis, curvature localization, and energy dissipation relative to a reference force-based formulation.

Speaker



Utkarsh Yadav

Project Consultant | Simpson Gumpertz and Heger

ID 695: Coupling Generalized Runge-Kutta-Nyström (GRKN) time-integration schemes with a machine learning (ML) assisted multi-time-step (MTS) framework

4:20 PM – 4:40 PM

Author(s): Sun-Beom Kwon, Duke University; Arun Prakash, Purdue University

Almost all existing implicit and explicit time-integration schemes can be represented in the form of a Generalized Runge-Kutta-Nyström (GRKN) scheme. Large-scale problems in structural dynamics that require the resolution of multiple temporal scales can be solved using multi-time-step (MTS) methods that decompose the spatial problem domain into multiple subdomains and integrate each subdomain with a time-step and integration scheme that is suitable for capturing its response. However, a critical limitation of existing MTS methods is that they are based on enforcing continuity of velocities across the interface between subdomains. Consequently, the solution has erroneous drifts in displacements that show up as nonphysical gaps and overlaps between subdomains. In this work, we present a new MTS framework that simultaneously enforces velocity and displacement continuity (VCDC) between subdomains to overcome this drawback. Unconditional stability of the MTS solution is ensured by using a scalar auxiliary variable (SAV) to control the energy in the coupled system algorithmically. We present several numerical examples to show that solutions obtained using the new VCDC MTS coupling method are able to achieve greater accuracy for the same computational cost in comparison to single time integration schemes and existing MTS coupling methods.

Even though the proposed MTS framework produces stable and accurate solutions, it involves a computationally intensive 3-step process: 1) solve the decoupled subdomains individually, 2) compute Lagrange multipliers needed for coupling the subdomains together at the interface, and 3) update the subdomain solutions to satisfy continuity constraints. To circumvent this 3-step solution process, we use a machine learning (ML) approach to predict the Lagrange multipliers on the interface. Solutions generated using the proposed VCDC MTS framework are used to train an artificial neural network that uses state vectors from the subdomains as input and produces values of the Lagrange multipliers on the interface as output. Since the Lagrange multipliers act as distributed internal forces between subdomains, they may be interpreted as external forcing functions acting on each subdomain. Thus, the response of a particular subdomain due to the effect of the Lagrange multipliers may be obtained by simply treating it as an external force on that subdomain and solving it with conventional time-stepping. With this approach, all subdomains are solved and coupled simultaneously in a single pass without the need for a time-consuming 3-step process. Performance of this ML-assisted approach is compared to existing MTS methods in terms of stability, accuracy and computational cost using key numerical examples.

Speaker



Arun Prakash

Associate Professor | Purdue University

ID 701: Fourier Neural Operators for Structural Dynamics Models: Challenges, Limitations and Advantages of Using a Spectrogram Loss

4:40 PM – 5:00 PM

Author(s): Rad Haghi, Tufts University; Bipin Jairaj Gaikwad, Tufts University; Abani Patra, Tufts University

Fourier Neural Operators (FNOs) have emerged as promising surrogates for partial differential equation solvers, offering computational speedups of up to three orders of magnitude. However, their applicability to structural dynamics remains poorly understood, particularly for nonlinear, time-varying mechanical systems. This work presents the first systematic framework for evaluating FNO performance in mechanical systems, establishing clear guidelines for when these methods succeed or fail. We design controlled experiments using two-degree-of-freedom mass-spring systems with four configurations: linear, linear with stiffness softening, nonlinear (cubic stiffness), and nonlinear with softening. Each configuration is tested under low-frequency, high-frequency, and broadband forcing, with training datasets ranging from 64 to 4096 samples. This design isolates the effects of nonlinearity, temporal variation, and data availability on FNO accuracy. Our results show a clear separation. For linear systems, FNOs achieve near-perfect energy preservation and accurate frequency content representation regardless of system complexity. For nonlinear systems, however, FNOs fail consistently, exhibiting 30-50% energy loss and poor spectral accuracy regardless of training data volume. This failure is architectural: mode truncation discards high-frequency content generated by nonlinear harmonic interactions, creating an error floor that more data cannot overcome. We validate these findings on the IEA 15MW reference wind turbine, a system with hundreds of degrees of freedom. Despite this complexity, FNO predictions remain accurate because the turbine operates in a predominantly linear regime. The model successfully generalizes from operational and idling conditions to shutdown transients without explicit training, confirming that nonlinearity, not system size, determines FNO applicability. To address FNOs' inherent bias toward low frequencies, we introduce a spectrogram-based loss function that supervises both time and frequency domain errors. This approach eliminates artificial energy dissipation in linear systems and improves predictions for nonlinear systems, though it cannot fully overcome the limitations imposed by mode truncation. These findings provide practical guidance: FNOs excel for linear or weakly nonlinear systems with band-limited forcing, but alternative approaches are needed when strong nonlinearities generate substantial harmonic content.

Speaker



Rad Haghi

University Researcher | Tufts University

ID 739: Bi-Fidelity Variational Inference for Data-Driven Equation Discovery

5:00 PM – 5:20 PM

Author(s): Damilola Adebayo, Northern Arizona University; Jamie Dellwardt, Northern Arizona University; Rajdip Nayek, Indian Institute of Technology, Delhi; Subhayan De, Northern Arizona University

The discovery of governing equations for physical systems has been a central theme of scientific investigation for a long time. Despite major advancements in data-driven modeling techniques, identifying governing equations for complex systems remains difficult, especially in the presence of noise or when only a limited amount of high-fidelity data is available. To alleviate this issue, this study presents a bi-fidelity framework for equation discovery that integrates a bi-fidelity approach with Bayesian variational inference within a latent space. A Conditional Variational Autoencoder (CVAE), conditioned on the temporal variable, is utilized to provide nonlinear coordinate transformations that facilitate efficient dimensionality reduction but keeping vital information about the system dynamics. While low-fidelity data is used for CVAE pretraining, subsequently high-fidelity data is utilized to refine it. Subsequently, variational inference is used to find the governing equations. Numerical experiments on dynamical systems show the efficacy of the proposed bi-fidelity approach to consistently retrieve sparse governing equations similar to the true ones.

Speaker



Damilola Adebayo

Graduate Research Assistant | Northern Arizona University

ID 860: Accelerating finite element solvers for parametric PDEs using low-fidelity neural surrogates

5:20 PM – 5:40 PM

Author(s): Victor Alcantara-Arias, California Polytechnic State University, San Luis Obispo; Amuthan Ramabathiran, California Polytechnic State University, San Luis Obispo

We propose a simple algorithm to accelerate the finite element analysis of parametric Partial Differential Equations (PDEs) using low-fidelity neural surrogates trained on coarse finite element meshes. We focus attention on problems of the many-query type where the goal is to compute the solution of PDEs that depend on parameters, functions in our case, when these parameters are sampled from known distributions. Neural operators have been extensively studied as potential surrogates for problems of this type in the scientific machine learning literature. Despite remarkable advances on this front, there remain several important challenges like high training cost, poor generalizability, lack of rigorous error control, and an overarching non-interpretability issue that attends most neural networks based methods. In this work, we retain the finite element method as the primary numerical technique, but use data driven surrogates like neural operators to obtain a good parameter-dependent initial guess for the finite element solver. The use of the finite element method is advantageous on two fronts: (i) it overcomes several of the shortcomings of data-driven approaches, including lack of interpretability, and (ii) there are much weaker requirements on the fidelity of the neural operators since the predictions of the neural operators are not directly used for the final inference. We employ a variety of different neural surrogates ranging from naive deep neural network to different types of neural operators to this end. We thus position our approach as a data-driven acceleration technique for the finite element method where the data-driven surrogates are only used in a supporting role. This algorithmic design choice allows the use of lower-fidelity neural surrogates, which we train using finite element simulations of the parametric PDEs on meshes that are much coarser than what are actually used in typical applications. This saves computational cost both for generating the training dataset and for the actual neural surrogate training itself. We use standard finite element interpolation to extrapolate the predictions of the neural surrogates on the coarse mesh to the fine mesh used in the test simulations, and use this extrapolated solution as an initial guess for the finite element solver. We present several applications involving parametric PDEs that illustrate the superior numerical performance of our proposed algorithm. For the choice of neural surrogates, we present a comparison of several neural surrogates ranging from naive neural networks to operator learning techniques like deep operator networks and neural operators. Overall, our approach presents an alternative to physics-informed machine learning—rather than focusing on replacing highly performant numerical methods like the finite element method, we focus on improving their efficiency using tools developed in the scientific machine learning literature. The approach we present is flexible and can be readily integrated with open-source finite element libraries. In summary, our method retains all the advantages of traditional scientific methods like the finite element method, notably interpretability, while at the same time increasing their efficiency.

Speaker



Amuthan Ramabathiran

Assistant Professor, Aerospace Engineering | Cal Poly SLO

ID 1001: A 3D SciML Surrogate for Mitral Valve Regurgitation Simulation

5:40 PM – 6:00 PM

Author(s): Mohammad Hossein Kazemi, University of Illinois Urbana-Champaign; Weiheng Zhong, University of Illinois Urbana-Champaign; Jing Bi, Dassault Systèmes; Victor Oancea, Dassault Systèmes; Hadi Meidani, University of Illinois Urbana-Champaign

High-fidelity finite element (FE) simulation of mitral valve mechanics is essential for understanding valvular function and guiding surgical or device design, but such simulations remain computationally expensive and impractical for large parametric studies or real-time clinical applications. This work presents an attention-based neural operator surrogate modeling framework for rapid prediction of mitral valve leaflet kinematics across the cardiac cycle. The proposed model learns a geometry-to-response operator that maps patient-specific valve mesh geometry and time to full-field three-dimensional leaflet displacements. Using a dataset of six hundred high-resolution FE simulations of mitral valves with varying anatomical geometries, we develop a feature-wise linearly modulated, parameter-conditioned neural operator architecture that leverages attention-based geometry interaction and parameter-aware decoding to predict full-field nodal displacements. We will show that the accuracy of the proposed neural operator across unseen geometries, preserving key biomechanical characteristics of mitral valve function, including asymmetric leaflet motion and heterogeneous deformation patterns.

Speaker



Hadi Meidani

Associate Professor | University of Illinois Urbana-Champaign

MS 033: Nondestructive testing-based damage identification using machine and deep learning

4:00 PM – 6:00 PM | Location: HUMN 1B90

Chair(s): Chanseok Jeong; Fernando Moreu; Hoon Sohn; Young-Jin Cha

Moderators



Chanseok Jeong

Associate Professor | Central Michigan University

ID 208: Hidden defect detection in coated steel using time-frequency analysis of pulse thermography

4:00 PM – 4:20 PM

Author(s): Hyeonjin Kim, Korea Advanced Institute of Science and Technology; Yongmin Kim, Korea Advanced Institute of Science and Technology; Hanbi Byun, Agency for Defense Development; Jaeseung Kim, LIG Nex1; Hyunsung Hwang, LIG Nex1; Hoon Sohn, Korea Advanced Institute of Science and Technology

Ensuring the structural integrity and long-term durability of steel infrastructure is a critical priority in civil and mechanical engineering. As these structures age, the early detection of hidden defects, such as backside corrosion and localized thinning, becomes essential to prevent catastrophic failures and extend service life. However, these defects are typically concealed beneath protective coatings, making visual inspection impossible and traditional non-destructive evaluation (NDE) methods highly labor-intensive. In this context, developing an automated, high-fidelity NDE technique for detecting hidden defects is not merely a technical advantage but a fundamental requirement for ensuring the public safety and reliability of steel infrastructures. Pulse Thermography (PT) has emerged as a candidate for such inspections due to its non-contact, wide-area, and rapid measurement capabilities. Nevertheless, its practical application to coated steel is significantly hindered by the high thermal diffusivity of the steel substrate and the thermal impedance of the coating layer. These physical properties lead to rapid heat dissipation and significant phase distortions, which often mask the subtle thermal signatures of subsurface defects. Consequently, conventional analysis methods struggle to distinguish actual degradation from environmental noise or variations in coating thickness, limiting their effectiveness in real-world field conditions.

To overcome these challenges, this study proposes a hybrid time-frequency domain analysis algorithm designed to enhance defect detectability and enable quantitative assessment. In the time domain, a Savitzky-Golay filter is employed to suppress stochastic noise while preserving transient thermal features. The signals are then processed in the frequency domain using Fast Fourier Transform (FFT) and Cross-Spectral Density (CSD) to extract phase contrast maps. These phase-based features provide inherent robustness against non-uniform excitation and surface emissivity variations compared to raw temperature data. The technical core of this research is the automated identification of a crossover frequency through phase-frequency responses. This frequency serves as a physical threshold to decouple the high-frequency thermal response of the coating from the low-frequency response of the steel substrate. Leveraging this decoupling, a linear calibration model compensates for phase distortions induced by uneven coating thickness, allowing for high-fidelity visualization of hidden defects regardless of surface conditions.

Experimental results on coated steel specimens demonstrate that the proposed multi-domain approach yields superior Contrast-to-Noise Ratio (CNR) compared to standard Pulsed Phase Thermography (PPT) and Thermal Signal Reconstruction (TSR). A strong linear correlation was established between the calibrated phase values and the actual residual thickness, validating the potential for automated, quantitative inspection in field environments. This physics-based framework provides a practical solution for monitoring the structural health of steel infrastructure under complex coating conditions.

Speaker



Hoon Sohn

Professor | KAIST

ID 259: Machine Learning and Advanced Sensor Systems to monitor and predict the impact of water-induced corrosion on the integrity of long-distance mild steel oil pipelines: A review

4:20 PM – 4:40 PM

Author(s): Oluwatoyin Joseph Gbadeyan, Collin College, Allen Texas

The integrity of long-distance mild steel oil and gas pipelines is under constant threat from electrochemical corrosion, a primary driver of catastrophic failures leading to significant economic and environmental damage. This review provides a comprehensive analysis of the technologies used for pipeline integrity management, tracing the evolution from periodic inspection to continuous, predictive monitoring. We present a critical comparison of the industry's cornerstone In-Line Inspection (ILI) technologies; Magnetic Flux Leakage (MFL) and Ultrasonic Testing (UT) analyzing their complementary physical principles and critical limitations. The review further investigates advanced external and long-range monitoring systems, including Guided Wave Ultrasonic Testing (GWUT), Acoustic Emission (AET), and Distributed Fiber Optic Sensing (DFOS), which are essential for real-time applications. A central argument of this paper is that these advanced sensor systems, while powerful, create a significant "big data" bottleneck. This "data overload" problem, characterized by extreme volume (from UT and DFOS) or complexity (from MFL and GWUT), establishes a distinct research gap that Machine Learning (ML) is now positioned to solve. We analyze the application of ML models for diagnosis (e.g., CNNs for MFL signal classification and SVMs for UT data) and prognosis (e.g., FEA-ANN hybrid models for rapid burst pressure prediction). Finally, this review identifies key gaps for future research, focusing on the need for non-contact sensors (like EMATs), the development of true multimodal data fusion models, and the validation of ML models on real-world, noisy sensor data.

Speaker



Oluwatoyin Joseph Gbadeyan

Professor | Collin College

ID 326: Identification of delamination of arbitrary geometries in 3D layered anisotropic composite structures via ultrasonic wave measurement and machine learning

4:40 PM – 5:00 PM

Author(s): Boyoung Kim, Central Michigan University; Chanseok Jeong, Central Michigan University

We present a convolutional neural network (CNN) framework for detecting subsurface delamination in three-dimensional anisotropic composite structures using elastodynamic wave measurements. The method employs a grid-wise classification strategy that estimates defect probabilities at each grid element, enabling accurate spatial localization of internal damage. Training data are generated through high-fidelity simulations in ANSYS Mechanical, where wave propagation in orthotropic composite layers bonded to isotropic materials is modeled with randomly introduced delaminations. Each sample consists of time-domain sensor-recorded wave responses as inputs and corresponding damage probability maps defined on a fixed background grid at the layer interface as outputs, with the grid configuration held constant throughout data generation. The proposed CNN learns to map measured waveforms to predicted damage probability fields, thereby identifying and localizing internal delaminations. To address severe class imbalance inherent in the binary classification problem, we introduce an alternative performance metric, Class-Weighted Accuracy (CWA). The framework is validated using both in-distribution test sets and out-of-distribution damage scenarios unseen during training, demonstrating strong generalization in detecting delaminations with diverse shapes, numbers, and locations. Numerical results indicate that increasing the number of sensors and the size of the training dataset enhances detection accuracy; training with noisy data improves robustness under noisy measurement conditions; and high accuracy can be achieved even when only out-of-plane measurements are available. Overall, the proposed approach provides a robust and scalable nondestructive evaluation method for composite materials without requiring prior knowledge of internal defect characteristics.

Speaker



Chanseok Jeong

Associate Professor | Central Michigan University

ID 328: Deep learning–based ultrasonic imaging for detection and localization of hidden defects within irregular-shaped structures

5:00 PM – 5:20 PM

Author(s): Boyoung Kim, Central Michigan University; Chanseok Jeong, Central Michigan University

This paper proposes a data-driven framework for the imaging and detection of hidden defects within irregular-shaped structures using ultrasonic waves. This approach utilizes wave responses measured at surface-boundary sensors to identify internal structural anomalies. To train the network, synthetic data are generated through numerical simulations that model the propagation of elastic waves using unstructured mesh, discretizing irregular-shaped structures, with randomly distributed defects. For labeling output features, the domain is represented by a background mesh consisting of grid elements, where each element is categorized as either damaged or undamaged through a grid-wise classification approach. This methodology is particularly advantageous as it eliminates the need for prior information regarding the number, size, or specific morphology of the target defects. The network is trained to map the measured wave responses to the corresponding grid-wise damage probability maps, which are projected onto the background mesh to reconstruct and localize the hidden defects. Numerical results demonstrate that the proposed method successfully identifies internal defects with irregular geometries that were not encountered during training. The presented framework exhibits high adaptability for modeling complex engineering structures and provides a robust solution for the nondestructive testing (NDT) of various industrial components.

Speaker



Boyoung Kim

Postdoctoral Researcher | Central Michigan University

ID 382: Non-Destructive Structural Damage Identification: A Systematic Review

5:20 PM – 5:40 PM

Author(s): Elaheh Mohammadhah, University of Manitoba; YoungJin Cha, University of Manitoba

Subsurface damage initiates and evolves within structural systems long before it becomes visible at the surface; however, its detection remains one of the most significant challenges in structural health monitoring. The ability to detect, quantify, and localize internal deterioration—such as microcracking, delamination, voids, reinforcement corrosion, and material degradation—requires a comprehensive understanding of both the physical mechanisms governing damage evolution and the sensing modalities capable of interrogating the structural interior without causing harm. This systematic review synthesizes the fundamental principles, mechanics-informed interpretation frameworks, and practical capabilities of non-destructive testing (NDT) methods for subsurface damage identification in civil infrastructure.

The review begins with stress-wave-based NDT techniques, including ultrasonic pulse velocity, guided wave propagation, phased-array ultrasonics, impact-echo, and acoustic emission. For each method, wave scattering, mode conversion, frequency dispersion, and attenuation phenomena induced by internal flaws are examined, with explicit links to damage characterization metrics and sensitivity limits imposed by material heterogeneity. Electromagnetic subsurface methods, such as ground-penetrating radar (GPR) and radiographic testing (X-ray and gamma-ray), are then reviewed in terms of dielectric and density contrasts, penetration depth, and resolution thresholds relevant to reinforced concrete and composite structures. Thermal-based approaches, including active and passive infrared thermography, are evaluated through the lens of heat transfer mechanisms, subsurface thermal contrast generation, and environmental dependencies. Additional modalities, such as electrical resistivity tomography and magnetic flux leakage, are analyzed with respect to their ability to infer moisture transport, corrosion activity, and internal material state variations. Vibration-based and modal analysis methods are also reviewed for their capacity to infer system-level stiffness changes and alterations in dissipative properties associated with internal damage mechanisms.

Beyond method-specific mechanics, the review examines emerging trends in inverse problem formulation, multisensory data fusion, and data-driven interpretation strategies. These include the integration of machine learning with physics-based models to enhance robustness, reliability, and uncertainty quantification in subsurface damage inference. Key challenges—such as boundary condition variability, scale effects, and noise sensitivity in field deployments—are discussed alongside opportunities for incorporating multispectral sensing into unified structural health monitoring frameworks.

Overall, this systematic review consolidates existing knowledge on subsurface NDT methods through a mechanics-informed perspective, providing critical insight into current limitations and identifying future research directions for advancing subsurface structural damage identification.

Speaker



Elaheh Mohammadhah

Ms. | University of Manitoba

ID 233: A Continuum Framework for Undamageable Materials: Hyperelastic Limits, Biological Benchmarks, and Multiscale Implications

5:40 PM – 6:00 PM

Author(s): George Z. Voyiadjis, Louisiana State University; Peter I. Kattan, Petra Books

This work introduces a unified continuum framework for undamageable materials, formulated as the asymptotic limit of a parameterized nonlinear elastic family in which the effects of damage progressively vanish. Motivated by the remarkable fatigue resistance and recoverability of biological tissues, the model reinterprets material degradation not as an inevitable process but as a mathematically suppressible mechanism. Building on classical hyperelasticity, we develop a family of constitutive responses indexed by an integer n , where damage enters only through a scalar modulation applied to the stress. As $n \rightarrow \infty$, this modulation tends uniformly to unity, eliminating the influence of damage and producing a purely elastic, undamageable limit that remains stable, frame-indifferent, and polyconvex under standard assumptions. The theory thus defines a continuous path from conventional elastic-damage models to a new class of hyperelastic materials immune to degradation.

To contextualize the physical relevance of this limiting model, we compare the undamageable hyperelastic response with experimental data for aortic tissue under cyclic tensile loading and swine brain tissue in uniaxial tension. The heart-tissue example demonstrates how biological systems achieve near-perfect elasticity over large deformation ranges through reversible fiber realignment and hierarchical structuring. The undamageable model reproduces the low- and mid-strain response with notable accuracy, capturing the transition from elastin-dominated compliance to collagen stiffening without invoking microcrack evolution. Similarly, the comparison with brain-tissue data confirms that the undamageable limit provides an excellent approximation up to moderate strains, matching the quasi-exponential stress-strain character observed experimentally. Deviations at high strains reveal zones where natural tissues activate viscoelastic relaxation or microstructural yielding—precisely the mechanisms absent from the idealized limit model—thus providing quantitative insight into the boundary between recoverable and irreversible biological behavior.

The proposed framework offers a mathematically rigorous and physically motivated tool for interpreting biological resilience, designing novel bioinspired materials, and bridging continuum damage mechanics with next-generation elastic formulations. By eliminating the need for a damage evolution equation while preserving full nonlinear behavior, the undamageable limit opens new possibilities for materials that maintain structural integrity under extreme or repeated loading. The results presented here suggest a promising direction for engineering systems with biological levels of durability and self-preservation.

Speaker



George Voyiadjis

Boyd Professor | Louisiana State University

MS 050: Mechanics of Network Materials: Linking Structure, Dynamics, and Function

4:00 PM – 6:00 PM | Location: CLUB 4-5

Chair(s): Frank Vernerey; Nikolaos Bouklas; Trisha Sain; Noy Cohen

Moderators



Trisha Sain

Associate Professor | Michigan Technological University



Noy Cohen

Professor | Technion - Israel Institute of Technology

ID 52: Critical-Strain Creep Failure in a Model Colloidal Gel

4:00 PM – 4:20 PM

Author(s): Florence Müller, California Institute of Technology; Julien Bauland, ETH Zurich; Theo Tervoort, ETH Zurich; Leon Govaert, Eindhoven University of Technology; Jan Vermant, ETH Zurich

Catastrophic failure in soft particulate systems—such as soil liquefaction and avalanches—often occurs under constant stress. However, predictive models for these processes remain limited. A widely known framework for describing failure under sustained stress is the empirical Monkman-Grant relation, which captures that plastic failure occurs when the accumulated plastic strain during the plateau creep phase reaches a critical threshold. This relation captures the trade-off between the rate of plastic deformation and material lifetime: higher applied stress leads to faster steady-state creep and earlier failure. While the Monkman-Grant relation has been extensively used to predict time-to-failure in metals and polymers, its relevance to particulate systems remains relatively unexplored. In this study, we investigate its applicability using a thermoreversible colloidal gel composed of rough particles as a model particulate system. Creep experiments conducted under varying stress levels reveal that the gel exhibits plateau creep consistent with stress-activated flow. Moreover, failure consistently occurs at a critical accumulated strain, in line with the Monkman-Grant relation. These findings extend the applicability of the Monkman-Grant relation to weak colloidal gels, providing a potential predictive framework for failure in both natural and engineered particulate materials.

Speaker



Florence Muller

Caltech

ID 474: Predicting Hydrolytic Aging of Vitrimers via A Coupled Reaction–Diffusion Network Theory

4:20 PM – 4:40 PM

Author(s): Md Rezaul Karim, Michigan Technological University; Trisha Sain, Michigan Technological University

Vitrimers have emerged as a promising class of polymer networks that bridge the gap between thermosets and thermoplastics by exhibiting thermoset-like mechanical integrity at low temperatures and reprocessability and self-healing above their topological freezing temperature. Despite growing interest, predictive constitutive frameworks that capture their nonlinear, time- and temperature-dependent behavior—particularly under finite deformation and long-term environmental degradation—remain limited. In this work, we present a unified, physics-based constitutive modeling framework for vitrimers that integrates transient network mechanics, deformation-dependent bond exchange kinetics, diffusion-driven chain dynamics, and chemically induced network degradation due to hydrolysis. The model is formulated within the transient network theory, leveraging the statistical mechanics of evolving polymer networks to describe vitrimer viscoelasticity across multiple time scales. Short-term nonlinear viscoelastic behavior is captured through a deformation-dependent evolution of bond exchange reaction kinetics under finite deformation, while long-term network mobility is incorporated via a diffusion-controlled kinetic term governing slower chain dynamics. The framework is further extended to vitrimer nanocomposites by incorporating filler-induced modifications to network mechanics. To address long-term durability, we develop a thermodynamically consistent coupled reaction–diffusion–mechanical formulation to model hydrolysis-driven degradation in glassy vitrimer networks. The diffusion of water, the scission kinetics of the ester bonds and the evolving network topology are explicitly coupled to the transient deformation mechanics. Two kinetic evolution laws are introduced for the extent of reaction, including an empirically calibrated ester concentration–based model informed by FTIR measurements of ester decay in epoxy–anhydride vitrimers. Hydrolysis-induced chain scission is linked to the evolution of the chain-length distribution, enabling a statistically motivated description of microstructural degradation and regions susceptible to void nucleation without prescribing explicit damage geometry.

The formulation implemented numerically via user-defined subroutines in ABAQUS/Standard, enabling fully coupled finite-element simulations of vitrimer and vitrimer-composite systems. The model predictions show good agreement with the experimental observations, including stress relaxation, creep, loading–unloading behavior, and hydrolysis-induced embrittlement in a range of temperatures and aging conditions. Overall, the proposed framework provides a comprehensive multiscale predictive tool that connects network chemistry, evolving topology, and macroscopic mechanical response, offering new insights into the long-term performance and sustainability of vitrimer materials.

Speaker



Trisha Sain

Associate Professor | Michigan Technological University

ID 655: Unifying Mechano-Sorptive Phenomena in Polymers : From Environmental Stress Cracking to Mechano-Sorptive Creep

4:40 PM – 5:00 PM

Author(s): Yue Yan, Tennessee State University; Ranganathan Parthasarathy, Tennessee State University; Anil Misra, Florida International University; Paulette Spencer, University of Kansas; Viraj Singh, SLB

Mechano-sorptive phenomena (MSP) represent the coupled mechanical response of polymers under the simultaneous action of mechanical stress and fluid sorption. Historically, research in this area has been bifurcated into two seemingly disparate fields: Environmental Stress Cracking (ESC), characterized by localized brittle fracture, and Mechano-Sorptive Creep (MSC), characterized by transient bulk-sorption-driven large deformations. We present a comprehensive review that bridges these disconnected research tracks, illustrating that ESC and MSC are not isolated phenomena but rather represent extremes on a continuous spectrum of MSP.

The underlying mechanism for both behaviors is traced to solvent diffusion into the amorphous phase, which disrupts non-covalent interactions and molecular entanglements. We introduce a unified framework to categorize related behaviors such as Environmental Stress Yielding (ESY) and Mechano-Sorptive Creep Rupture (MSCR). Central to this review is the hypothesis that the reversible components of MSC can be explained through equilibrium network swelling, while capturing irreversibility necessitates either or both of sorption and strain rates as constitutive variables. Consequently, the order of stimulus – mechanical stress and solvent sorption does not affect the equilibrium creep and sorption unless irreversibility is involved. Furthermore, we propose and demonstrate that only the bound portion of the fluid in the polymer is associated with the irreversible portion of MSC.

We evaluate the applicability of analytical solutions to Mode-I two-dimensional viscoelastic fracture mechanics problems for e.g. Schapery's theory, Chudnovsky's crack layer theory, and the generalized J-integral in understanding the transition between brittle and ductile MSP failures. We also review state-of-the-art constitutive models, identifying the Transient Network Theory and the Tube-Junction theory as promising continuum constitutive theories with a sound molecular basis which can span the glass transition across loading frequency, temperature, stress, and solvent fraction. Finally, we discuss the implications of MSP in diverse applications—ranging from the durability of dental adhesives and aerospace components to the advantageous use of MSP in the self-assembly of block copolymer thin films. Our research serves as a roadmap for developing more predictive, multiscale material models for polymers undergoing physical interactions with fluids.

Speaker



Yue Yan

PhD Student | Tennessee State University

ID 781: From Chain Physics to Network Function: Multiscale Models for Responsive Hydrogel Mechanics

5:00 PM – 5:20 PM

Author(s): Noy Cohen, Technion - Israel Institute of Technology

In this talk, I present a unified multiscale framework, grounded in statistical mechanics, for understanding and predicting the mechanical and stimuli-responsive behaviors of polymer hydrogels. I focus on two widely used systems: (1) poly(ethylene glycol) diacrylate (PEGDA) networks, where compliant PEG chains interact via stiff polyacrylate rods, and (2) poly(N-isopropylacrylamide) (PNIPAM) networks, which undergo a coil-to-globule transition near a characteristic temperature. These distinct microstructures give rise to unique network responses: PEGDA networks display tunable stiffness and extensibility, while PNIPAM networks show temperature-dependent swelling and de-swelling, and, under mechanical constraints, exhibit phase coexistence of swollen and collapsed regions. By connecting chain-level physics to network-scale behavior, this work establishes design principles for engineering hydrogels with tailored mechanics and adaptive responses. The findings provide insights that are useful to a wide array of applications, including soft robotics, biomedical devices, and responsive materials.

References

1. M. Levin, Y. Tang, C. D. Eisenbach, M. T. Valentine, and N. Cohen, "Understanding the Response of Poly(ethylene glycol) diacrylate (PEGDA) Hydrogel Networks: A Statistical Mechanics-Based Framework", *Macromolecules*, 57 (15), 7074–7086, 2024.
2. M. Levin and N. Cohen, "Thermo-Mechanics of PNIPAM Gels: from a Single Chain to a Network Response", *Macromolecules*, 58 (10), 5187–5200, 2025.
3. N. Cohen, "Phase Coexistence in Thermo-Responsive PNIPAM Hydrogels Triggered by Mechanical Forces", *arXiv:2512.19464*, 2025.

Speaker



Noy Cohen

Professor | Technion - Israel Institute of Technology

ID 951: Experimental and Computational Assessment of Thermo-Oxidative Degradation in Semi-Crystalline Polyimides

5:20 PM – 5:40 PM

Author(s): Santiago Marin Jimenez, University of Colorado Boulder; Marwa Yacouti, University of Colorado Boulder; Maryam Shakiba, University of Colorado Boulder

This study characterizes the physical and chemical degradation mechanisms of thermo-oxidatively aged Kapton polyimide and establishes a constitutive framework to predict its mechanical response. Thermo-oxidative aging is one of the primary degradation mechanisms affecting high-performance polymers exposed to elevated temperatures in oxygen-rich environments. Prolonged exposure under these conditions promotes oxidative reactions that progressively alter the polymer microstructure, ultimately degrading mechanical performance and limiting service life. Semi-crystalline polyimides are widely used as structural materials in aerospace and aeronautical systems due to their outstanding thermal stability, chemical resistance, and mechanical strength; however, the mechanisms governing their long-term degradation remain insufficiently understood. A detailed understanding of the relationship between chemical degradation and macroscopic mechanical behavior is therefore essential for improving lifetime predictions of these materials.

This work presents a combined experimental and computational investigation of the effects of thermo-oxidative aging on PMDA-ODA polyimide films, commercially known as Kapton. Samples were aged in air at 300 °C for up to five weeks and subsequently characterized using uniaxial tensile tests, single edge notch test (SENT), tear test, X-ray diffraction (XRD), and Raman spectroscopy. This multi-technique approach enabled a systematic assessment of the mechanical, physical, and chemical changes induced by aging.

Mechanical testing revealed a progressive reduction in failure strain and tensile strength, accompanied by an increase in elastic stiffness. Fracture experiments under Mode I and Mode III loading conditions demonstrated a pronounced decrease in fracture toughness, indicating a transition toward increasingly brittle behavior with aging time. These macroscopic trends were consistent with the microstructural and chemical modifications identified through material characterization. XRD measurements suggested an increase in crystallinity, while Raman spectroscopy provided evidence of oxygen diffusion into the polymer matrix and degradation of specific molecular bonds. Together, these observations indicate that thermo-oxidative aging promotes both chain scission and crosslinking, mechanisms that restrict molecular mobility and compromise the integrity of the polymer network.

Building on these experimental findings, a constitutive framework was developed that incorporates degradation indicators derived directly from XRD and Raman spectroscopy into a viscoelastic-viscoplastic formulation. The proposed model accurately reproduces the stress-strain response of aged films without requiring mechanical recalibration for each aging condition, enabling a more physically grounded prediction of material behavior. This experimental-computational strategy establishes a predictive framework for assessing the long-term mechanical performance of semi-crystalline polyimides operating in high-temperature oxidative environments and provides new insight into the molecular processes governing thermo-oxidative degradation.

Speaker



Santiago Marin Jimenez

Research Assistant | University of Colorado Boulder

ID 547: Linking Biopolymer-Mineral Interactions to Printability and Performance in 3D-Printed Earth

5:40 PM – 6:00 PM

Author(s): Samuel J. Armistead, University of Colorado Boulder; Yierfan Maierdan, Columbia University; Olga B. Carcassi, Columbia University; Rebecca A. Mikofsky, University of Colorado Boulder; Shiho Kawashima, Columbia University; Lola Ben-Alon, Columbia University; Wil V. Sruar III, University of Colorado Boulder

Speaker



Samuel Armistead

Research Associate & Lecturer | University of Colorado, Boulder

MS 087: 11th Symposium on Molecular Scale Modeling and Experimentation

4:00 PM – 6:00 PM | Location: CASE E230

Chair(s): Dinesh Katti; Sinan Keten; Nima Rahbar; Kalpana Katti; Steven Cranford; Wenjie Xia

Moderatorss



Wenjie Xia

Associate Professor | Iowa State University



Dinesh Katti

Professor | North Dakota State University

ID 825: Molecular Insights into the Mechanical and Interfacial Behaviors of Functional Polymers

4:00 PM – 4:20 PM

Author(s): Wenjie Xia, Iowa State University

The outstanding thermomechanical and interfacial properties of functional polymers make them desirable for thin film and coating applications. In this work, we present multiscale modeling approaches to explore the nanoscale mechanical responses during the interfacial and deformational processes. We introduce a temperature-transferable coarse-grained model of polymers using the energy renormalization method to overcome the temporal and spatial limitations of atomistic modeling while preserving their thermomechanical response. By systematically evaluating the influence of temperature, cross-linking density, and other key parameters on the surface deformation behavior of polymer films, we aim to elucidate their interfacial behavior at the nanoscale. This research provides critical insights for experimental investigations and coating design, advancing the development of high-performance functional polymers for various applications.

Speaker



Wenjie Xia

Associate Professor | Iowa State University

ID 881: Label-Free Separation of microRNA Signatures via Raman Spectroscopy and Spectral Unmixing

4:20 PM – 4:40 PM

Author(s): Dinesh Katti, North Dakota State University; Benjamin Vahidi Pashaki, North Dakota State University; Hanmant Gaikwad, North Dakota State University; Jeon Woong Khang, Massachusetts Institute of Technology; Peter T.C. So, Massachusetts Institute of Technology; Ramasamy Paulmurugan, Stanford University; Dorian Liepmann, University of California Berkeley; Renugopalakrishnan Venkatesan, Northeastern University; Kalpana Katti, North Dakota State University

MicroRNAs (miRNAs) are short, non-coding RNA molecules that regulate gene expression and influence key biological processes, including development, cell proliferation, and oncogenic signaling. Dysregulated miRNA expression is strongly associated with cancer progression, making these molecules important diagnostic and prognostic biomarkers. Despite their significance, reliable detection of miRNAs in realistic biological environments remains challenging due to their short sequences, structural similarity to other nucleic acids, and spectral congestion in complex mixtures. Spontaneous Raman spectroscopy provides a powerful label-free method for probing nucleic-acid structure and has shown strong potential for miRNA profiling. Distinct vibrational signatures arising from the phosphodiester backbone reflect hybridization stability and can differentiate RNA from DNA conformations. These intrinsic structural markers form a solid foundation for identifying nucleic-acid species. Still, their application in diagnostic settings requires analytical approaches capable of managing overlapping signals from heterogeneous sample compositions. In this work, we integrate Raman spectrochemical analysis with machine-learning-based signal processing to develop a robust platform for resolving miRNAs within complex nucleic-acid mixtures. Raman spectra were acquired from sample sets containing cancer-associated miRNAs, messenger RNAs (mRNAs), and DNA oligonucleotides to emulate clinically relevant molecular complexity. To analyze the resulting data, we constructed a custom MATLAB pipeline that automates baseline correction and applies blind signal-unmixing algorithms to disentangle congested spectral regions. Our findings indicate that Raman backbone markers reliably validate the hybridization state and structural identity of isolated nucleic-acid species; however, these markers alone cannot overcome the extensive spectral overlap present in mixed samples. The computational pipeline proved essential for resolving these overlaps. Machine-learning-based unmixing successfully deconvoluted intricate spectral profiles and extracted distinct vibrational signatures of cancer-associated miRNAs even in the presence of strong mRNA and DNA interference. The high fidelity of this separation demonstrates the effectiveness of combining physical spectral markers with data-driven analysis. Overall, this study establishes a scalable and accurate framework for high-throughput, label-free detection of miRNAs in biologically complex environments. By coupling spontaneous Raman spectroscopy with automated signal-unmixing methods, we provide a pathway toward practical diagnostic biosensing platforms that isolate clinically relevant miRNA signals without the need for fluorescent labels.

Speaker



Dinesh Katti

Professor | North Dakota State University

ID 659: Multi-scale mechanical model for Tungsten in plasma facing components (PFCs) of nuclear fusion reactors

4:40 PM – 5:00 PM

Author(s): Ranganathan Parthasarathy, Tennessee State University; Mohammed Alnaggar, Oakridge National Laboratory; Lin Li, Tennessee State University; Anil Misra, Florida International University

In a Tokamak fusion reactor, heat and fusion products are directed away from the plasma towards the diverter. The by-products of the deuterium-tritium fusion are neutrons and helium. The plasma facing components (PFCs) of the diverter should consequently endure high heat flux, neutron irradiation and helium bombardment. Tungsten is the material of choice in the PFCs because of its high melting point, thermal conductivity, recrystallization temperature, and low sputtering yield. However, the harsh operating conditions will gradually degrade Tungsten's ductility, drive tungsten dust contaminants into the plasma, and lead to catastrophic failure. The degradation of ductility, represented by an increase in the Brittle-to-Ductile Transition Temperature (BDTT), has been traced back to the embrittlement of grain boundaries (GBs), as in most metals. Therefore, a predictive computational model to assess the durability of tungsten or other PFC material under these conditions is critical for the design of a Tokamak fusion reactor. Prediction of the material level and structure level response of the PFC component material to these stimuli must necessarily originate from multi-scale models because the experimental effort required to construct appropriate phenomenological constitutive laws for macroscale continuum modeling is currently intractable. Moreover, multi-scale models explicitly incorporate the atomic scale mechanics at the GBs, thusly informing grain boundary engineering towards developing alloys with a decreased Brittle-to-Ductile Transition Temperature (BDTT). In this project, a workflow for the determination of traction-separation (TS) curves for GBs including special Coincident Site Lattice (CSL) GBs in pure Tungsten based on molecular dynamics (MD) simulations using the Large Atomic/Molecular Massively Parallel Simulator (LAMMPS) is presented. The TS curves inform a multi-physics lattice discrete particle model (MP-LDPM) at the grain level, which in turn informs a macroscopic thermomechanics structure level model. A library of such TS curves is expected to correctly predict the nature of brittle failure in terms of intergranular versus transgranular fracture. Due to the use of MD for GBs, the presented approach also successfully captures critical phenomena such as bond trapping that influence GB fracture. The approach is currently limited in its ability to correctly predict plastic dissipation since the spatial and temporal scales accessible by MD are insufficient to model the evolution of dislocation networks across multiple grains. However, a future strategy to incorporate dislocation dynamics within MP-LDPM to remedy this shortcoming will also be presented.

Speaker



Ranganathan Parthasarathy

Associate Professor | Tennessee State University

ID 882: Nanoclays in Regenerative Medicine

5:00 PM – 5:20 PM

Author(s): Kalpana Katti, North Dakota State University; Dinesh Katti, North Dakota State University; Priyanka Kumari, North Dakota State University; Pooyan Vahidi Pashaki, North Dakota State University; Benjamin Vahidi Pashaki, North Dakota State University; Hanmant Gaikwad, North Dakota State University; Siva venkata Chaitanya Panduru, North Dakota State University

Clays have been reported to be used as for medicinal purposes early as 2500 BC with more recent uses in wound healing. Recently clays have emerged as potential components of biomaterials for tissue regeneration. The regenerative medicine approaches are being pursued for both tissue replacement in case of disease and injury. Simultaneously emerging areas include the use of biomaterial-based engineered tissues as testbeds of human diseases. We illustrate the use of clays in nanosized formulations of amino acid modified montmorillonite to elicit favorable and tunable mechanical as well as biological activity through enabling mesenchymal stem cells to differentiate into osteoblastic lineages for creation of bone as well as tenocytes for creation of ligaments. The engineered bone tissue is used for both regenerative medicine as well as its use in design of testbeds of prostate and breast cancer bone metastasis using patient derived cancer tissues. In particular we report studies in design of bone replacement tissues using modified nanoclay composites with degradable polymers with tuned and controlled mechanical properties. In addition, we report the use of modified nanoclays for design of anterior crucial ligaments biomaterials and for repair of the ligaments. Molecular dynamics simulations probe the interaction between clay surfaces and integrin molecules- the primary perpetrators of cell adhesion. Extensive molecular modeling studies elucidate the activation of integrins with use of the nanoclays, thus illustrating the outside in signaling given by nanoclays to the cells.

Speaker



Kalpana Katti

University Distinguished Professor | North Dakota State University

ID 564: The Effect of Carbon Nanofibers on the Microstructure, Chemistry, and Pore Structure of Concrete Made with Fine Recycled Concrete Aggregates

5:20 PM – 5:40 PM

Author(s): Giovanni Dal Poggetto, NCSU; Ange-Therese Akono, NCSU

Recycled aggregate concrete (RAC) is produced using recycled concrete aggregates (RCAs) obtained from crushed old concrete. Although RCAs offer a sustainable alternative to natural aggregates, the poor durability and mechanical performance of RAC limit its widespread application. This study investigated the enhancement of RAC's durability and performance through the incorporation of carbon nanofibers (CNFs). A novel processing method was developed to prepare high-slump CNF-modified RAC, and its chemistry, pore structure, and microstructure were analyzed using backscattered scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS), X-ray powder diffraction (XRD), and mercury intrusion porosimetry (MIP). The results showed that CNFs significantly reduced the porosity and permeability, with a decrease in the porosity by 9.0 wt.% and a decrease in the water permeability by 39.3% at an optimal CNF dosage of 0.5% by weight. Furthermore, CNFs promoted the formation of calcium hydroxide and enhanced the densification of the calcium silicate hydrate (C-S-H) matrix, leading to improved resistance against environmental stressors. These findings provide a critical pathway for designing sustainable, high-durability RAC for structural applications.

Speaker



Giovanni Dal Poggetto

NCSU

ID 862: A micromechanics-informed interface damage model for numerical simulation of fracture in fiber-reinforced concrete

5:40 PM – 6:00 PM

Author(s): Pouriya Pirmoradi, Eindhoven University of Technology; Akke Suiker, Eindhoven University of Technology; Payam Poorsolhjoui, Eindhoven University of Technology

A numerical framework is presented for simulating fracture in fiber-reinforced concrete using interface elements to model crack initiation and propagation. The bulk material is represented by linear elastic continuum elements, while all nonlinear deformation, damage evolution, and energy dissipation are confined to interface elements governed by constitutive traction–separation laws. The load-bearing contribution and failure mechanisms associated with reinforcing fibers are incorporated directly at the interface level.

The tensile response of the interface explicitly accounts for fiber bridging mechanisms. The behavior of individual fibers is described by a micromechanical bridging model that captures debonding, sliding, pull-out, and fiber rupture. To represent the collective response of a large number of fibers crossing the interface at different orientations, this model is homogenized by integrating over the fiber orientation distribution and is then embedded into an effective interface traction–separation law. In addition, normal (tensile) and shear damage are coupled in a two-way manner, allowing damage evolution in one mode to influence the strength and stiffness degradation in the other. The compressive response of the interface is formulated consistently.

To improve numerical robustness and mitigate convergence issues associated with strain localization, the interface damage formulation is regularized through a rate-dependent extension. The proposed framework is validated using finite element simulations of fracture in engineering cementitious composite structures. The results demonstrate the influence of fiber orientation on load-carrying capacity, crack opening behavior, and fracture localization. Good agreement with experimental data from the literature confirms the ability of the model to capture key fracture mechanisms in fiber-reinforced cementitious composites.

Speaker



Payam Poorsolhjoui

Assistant Professor | Eindhoven University of Technology

MS 052: Stability of structures: Advances across time and scales

4:00 PM – 6:00 PM | Location: CASE E240

Chair(s): Noël Challamel; Hayder Rasheed; C.W. Lim; Stylianos Yiatros; Hyeyoung Koh

Moderatorss



C.W. Lim

Professor | Zhejiang University



Noël Challamel

Professeur | UNIVERSITE BRETAGNE SUD

ID 923: The Interplay of Steel Plate Bending and Rubber Cavitation on the Stability of Elastomeric Isolators

4:00 PM – 4:20 PM

Author(s): Eduardo Montalto, University of Colorado Boulder; Dimitrios Konstantinidis, University of California, Berkeley

Elastomeric seismic isolators are earthquake protective devices composed of interleaving rubber layers and steel reinforcement plates (shims). When subjected to earthquake loading, these devices experience large lateral deformations combined with high transient compressive loads due to the superstructure overturning moments and vertical ground motion. Under these loading conditions, elastomeric isolators exhibit limit-point type instabilities, representing a primary failure mode for the bearings. Despite the high relevance of this limit state, its cause has seldom been understood because of the complex mechanical behavior of the isolators when undergoing very large deformations. For design purposes, the buckling capacity of the bearings under pure compression is empirically reduced to estimate the stability limits under large lateral deformations. From a numerical perspective, semi-empirical models have represented the softening lateral response by assuming that steel plates are perfectly rigid and limiting the rubber capacity based on cavitation under large deformations, although there is no experimental evidence to support this. A recent experimental campaign by the authors, including component-level and system-level tests, demonstrated that reinforcement thickness affects the lateral response and stability of the bearings, indicating that reinforcement deformation plays a role in this phenomenon. The current work presents results from a finite element study that complements the experimental campaign by investigating localized effects in the steel and rubber layers that control the component-level stability of the bearings. Numerical simulations are initially validated against the experimental results. Additional bearing geometries are explored via a parametric study in which the rubber and steel layer properties are varied, with the objective of discerning when reinforcement bending or rubber damage due to cavitation governs the softening lateral response of the composite devices. Results from the numerical simulations shed new light on the localized effects governing the stability of elastomeric isolators, and open up new opportunities to pursue rational mechanics-based design and modeling approaches for these earthquake protective devices.

Speaker



Eduardo Montalto

Assistant Professor | University of Colorado Boulder

ID 66: Influence of Orthotropy on the Buckling of Multilayered Columns

4:20 PM – 4:40 PM

Author(s): Peter Kočman, University of Ljubljana, Faculty of Civil and Geodetic Engineering; Sabina Huč, University of Ljubljana, Faculty of Chemistry and Chemical Technology

This contribution presents an exact analytical approach for predicting the critical buckling load of three-dimensional multilayered orthotropic elastic columns. The formulation is based on the Simo–Reissner beam model and allows each layer to adopt its own constitutive behaviour and orthotropic orientation. In the following, longitudinal and cross-sectional orthotropy are examined in greater detail. Parametric results show that longitudinal orthotropy has a dominant influence on buckling resistance, whereas the effect of cross-sectional orthotropy remains comparatively minor. For cross-laminated timber (CLT) columns, the study highlights the importance of layering and fibre orientation. The proposed method generalises classical Euler-type buckling concepts to orthotropic and layered materials, offering an interesting tool for assessing the stability of advanced timber products and other laminated structural systems.

Acknowledgments:

This work was supported by the CRESTIMB project, funded by the Ministry of Higher Education, Science and Innovation of the Republic of Slovenia (Grant No. C3360-24-452017 and NRP No. 3360-24-0016) under the ForestValue2 programme, co-funded by the European Union's Horizon Europe research and innovation programme (Grant Agreement No. 101094340).

Speaker



Peter Kočman

Researcher | University of Ljubljana

ID 158: Nonlinear Analysis of Steel Deck Diaphragms Using the Instantaneous Center Method and Geometry-Specific Fastener Models.

4:40 PM – 5:00 PM

Author(s): Firaol Fekadu, Washington State University; Hyeyoung Koh, Washington State University

Shear strength of cold-formed bare steel deck diaphragm is influenced by the load-deformation response of the fasteners within the diaphragm, making the overall diaphragm behavior sensitive to fastener nonlinearity. The Instantaneous Center Method (ICM) has been adopted in AISC 360, Specification for Structural Steel Buildings, to predict the strength capacity of eccentrically loaded bolted and welded connections in hot-rolled steel construction. The method provides a mechanics-based framework that accounts for fastener nonlinearity by incorporating inelastic fastener load–deformation behavior. In this study, the ICM is applied to evaluate the shear strength of bare steel deck diaphragms using refined fastener load–deformation relationships. Experimentally based backbone curves for arc-spot welds and sheet-to-sheet screws are extracted from published test data, with key geometric parameters such as effective weld diameter, screw diameter, and deck thickness. These fastener load–deformation curves were implemented within the ICM framework to predict diaphragm shear strength capacities. Predicted diaphragm capacities were assessed through comparisons with experimental results reported in the literature, predictions based on elastic analysis methods referenced in AISI S100, North American Specification for the Design of Cold-Formed Steel Structural Members, and ICM predictions using simplified fastener load-deformation curves. The results show that incorporating refined fastener response models leads to improved agreement with experimental diaphragm strength and reduces overestimations observed in the ICM with simplified load-deformation curves. By explicitly accounting for fastener inelasticity and stiffness degradation, the proposed ICM framework provides improved representation of nonlinear load transfer within the diaphragm. The findings further demonstrate how degradation of fastener stiffness in the nonlinear response influences diaphragm limit states through loss of force equilibrium within the fastener group, showing how fastener-level nonlinearity influences overall diaphragm strength and motivates consideration of stability-related behavior arising from nonlinear response.

Speaker



Firaol Fekadu

Research Assistant | Washington State University

ID 548: Critical Twist for Slip Suppression in Defective Carbon Nanotube Bundles: An MD Study

5:00 PM – 5:20 PM

Author(s): Shahbaz Paramban, University of Missouri; Hessam Yazdani, University of Missouri

Carbon nanotube (CNT) bundles are governed less by the intrinsic strength of their constituents than by the efficiency of load transfer across intertube interfaces, where weak van der Waals-mediated shear can promote slippage and premature failure well before individual nanotubes reach their tensile capacity. Twisting has previously been proposed as an effective strategy to suppress intertube sliding and improve load transfer at the bundle scale. In this work, molecular dynamics simulations are used to quantify how CNT chirality and structural imperfections (vacancy defects, Stone–Wales defects, and disclination-induced voids) influence i) bundle tensile strength and ii) the efficacy of twisting in mitigating intertube slippage. Defect-free armchair CNT bundles exhibit the highest tensile strength of ~75 GPa at a failure strain of ~10%. Across the examined configurations, critical twist angles are identified beyond which intertube slippage is effectively suppressed, enabling more efficient load sharing among subsequent CNTs. Maximum intertube pull-out forces are also reported as a measure of interfacial sliding.

Speaker



Shahbaz Paramban

Graduate Research Assistant | University of Missouri, Columbia

ID 572: Buckling mode shapes of tape springs under axial compression

5:20 PM – 5:40 PM

Author(s): Jacob Tersigni, The University of Colorado Boulder; Jaynie Tercovich, The University of Colorado Boulder; Hideyuki Nakanishi, The University of Colorado Boulder; Francisco López Jiménez, The University of Colorado Boulder

Tape springs are thin-shell structures with a constant radius of curvature and an open cross-section, widely used in the aerospace industry to enable the in-space deployment of lightweight space structures. Tape springs may be used independently as slit-tube booms for positioning sensitive instruments, or as structural elements within larger deployable frame and truss structures to enable large antenna reflectors, solar arrays, solar sails, or solar energy transmission systems. Tape springs are highly desirable for such applications due to their ability to be flattened and rolled for compact stowage during launch, and deployed using stored strain energy. To minimize mass and accommodate the large strains induced during stowage, tape springs are typically manufactured from thin, high-strain composite materials. As a result, these open, thin-shell structures are highly susceptible to buckling.

While the buckling behavior of tape springs in bending has been studied extensively, their response under axial compression has received comparatively little academic attention. This loading condition is especially relevant when tape springs are used as load-bearing members within larger structural assemblies. In this work, we present a generalized characterization of axial buckling in tape springs under clamped end conditions, applicable across a wide range of geometries and use cases.

We show that the axial buckling response of tape springs falls into three distinct regimes governed by geometry – specifically, the radius of curvature, subtended angle, thickness, and length. Tape springs with small subtended angles relative to their length behave as slender columns as described by classical Euler–Bernoulli buckling theory. As the subtended angle increases, a torsional mode about the mid-plane of the tape spring dominates. For sufficiently large subtended angles, the primary buckling mode transitions again to a periodic mode involving only the free edges of the shell.

To capture these behaviors, we adapt classical thin-shell buckling formulations to the case of open cross-sections and clamped boundary conditions. Our analytical solutions for each buckling regime are generalizable across a wide range of tape spring geometries, and show strong agreement with finite element simulations. Experimental validation is performed for select geometries using tape springs manufactured from isotropic brass, as well as quasi-isotropic and anisotropic carbon fiber reinforced polymer composites more representative of state-of-the-art deployable space structures. Digital image correlation (DIC) is used to measure displacement and strain fields from initially linear compression, to the onset of buckling, through multiple nonlinear post-buckling regimes, and is directly compared to nonlinear finite element simulations. We also use DIC to quantify initial geometric imperfections that influence buckling behavior. Together, these results provide a framework for predicting axial buckling in tape springs as a function of geometry, offering practical design guidance for large, lightweight deployable structures in which tape springs serve as primary or secondary load-bearing elements.

Speaker



Jacob Tersigni

Graduate research assistant | The University of Colorado Boulder

ID 229: Stability of Multi-Storey Frames: Analytical Prediction of Exact Critical Loads

5:40 PM – 6:00 PM

Author(s): Peter Kočman, University of Ljubljana; Bojan Čas, University of Ljubljana

This contribution introduces a new analytical framework for computing the exact critical buckling load of multi-story, multi-compartment in-plane elastic frames. Unlike conventional approaches that rely on second-order theory, the proposed method employs a generalized linearization procedure that has previously been applied only to isolated columns. Its extension to complete frame assemblies is presented here for the first time. The accuracy of the formulation is assessed through comparison with published benchmark results, demonstrating excellent agreement with alternative analytical solutions. The practical relevance of the approach is illustrated through a parametric study, which elucidates the influence of imperfection sensitivity, crossbar-to-column stiffness ratios, and lateral support stiffness on the exact critical load. The findings confirm the method's effectiveness and provide new insight into the stability behavior of elastic frame structures.

Speaker



Bojan Čas

Associate Professor | University of Ljubljana

MS 030: Physics-based data-driven modeling and uncertainty quantification in computational science and engineering

4:00 PM – 6:00 PM | Location: KTCH 1B87

Chair(s): Bahador Bahmani; Ramin Bostanabad; Johann Guilleminot; Michael Shields; Wei Chen; Lori Graham Brady

Moderators



Bahador Bahmani

Assistant Professor | Northwestern University

ID 703: Microstructure informed data-driven damage model for ductile materials under dynamic loading conditions

4:00 PM – 4:20 PM

Author(s): Indrashish Saha, Johns Hopkins University; Lori Graham-Brady, Johns Hopkins University

Extreme environments are typically characterized by high temperatures and pressures and designing structures to operate under such conditions requires a clear understanding of material behavior in such conditions. High-velocity impact loading can generate such extreme environments, where spall failure is a common consequence. Spall failure arises from dynamic fracture driven by high hydrostatic tensile stresses generated by stress-wave interactions within the material. These tensile stresses promote the nucleation and growth of voids, which eventually coalesce and lead to fracture. The underlying microstructural features of the material strongly govern the nucleation and growth of voids. Consequently, an accurate description of spall behavior requires explicit consideration of characteristics such as average grain size, crystallographic texture, and void size. In this work, we aim to develop a microstructurally informed damage law using machine learning models, that is inferred from lower-scale simulations. These data-driven models are then embedded within a macroscale framework to simulate the structural response under impact loading through plate-impact simulations. By leveraging machine learning to extract damage evolution directly from lower-scale physics, this approach minimizes reliance on simplifying assumptions inherent in traditional physics-based formulations and provides a flexible and efficient pathway for incorporating complex microstructural effects into damage models.

Speaker



Indrashish Saha

Johns Hopkins University

ID 820: REAL-TIME INTERACTIVE SIMULATION OF BUILDING STRUCTURES FOR HIGH-RISK SCENARIOS

4:20 PM – 4:40 PM

Author(s): Nathan Bissonnette, Impulse Control

Application of real-time interactive simulation (RTIS) to building's response allows engineers and designers to quickly and iteratively study a structure's resilience under high-risk loading scenarios. An engineering algorithm is presented in which the structural building model is converted through industry-standard formats into a rigid body-spring assembly conditioned for Unity, a real-time development platform, with built-in physics for simulation. Physical member representatives are combined with the analytical model definition by superposition and joints are simulated with Havok physics, a highly performant middleware physics engine used in video games. The end result of the process is a physical model which stands under its own weight, sways back and forth when subjected to a disturbance, and returns to its equilibrium position unless a joint threshold is exceeded. Solution of an example UFC 4-023-03 problem demonstrates that consumer-grade technology is sufficient to simulate basic building response. RTIS of buildings presents two main challenges: constructing a representative, performant, physics-based model and ensuring the structural analysis yields interpretable, reliable results. These tools lay the fundamental groundwork for a considerable research and development effort to calibrate material properties and spring values, validate test cases, and program for a wide range of external forces which will provide tremendous benefits for assessment of progressive collapse, hardening of buildings against attack, and a more accessible understanding of building design for high-risk scenarios.

Proof-of-concept: https://store.steampowered.com/app/1691020/Bent_on_Destruction/

Speaker



Nathan Bissonnette

Engineer | Impulse Control

ID 836: Time-dependent density estimation of stochastic processes with classifiers

4:40 PM – 5:00 PM

Author(s): Agnimitra Dasgupta, Sandia National Laboratories; Ali Fardisi, University of Southern California; Javier Murgioito-Esandi, University of Southern California; Assad Oberai, University of Southern California

We propose a data-driven method to learn the time-dependent probability density of a multivariate stochastic process from sample paths, assuming that the initial probability density is known. Our method uses a novel time-dependent binary classifier trained using a contrastive learning-based objective. The classifier is trained to discriminate between realizations of the stochastic process at two nearby time instants, while the input to the final activation in the classifier is scaled by the gap between these time instants. By analyzing the objective, we show that the input before the final activation in the time-dependent classifier is a second-order approximation of the partial derivative, with respect to time, of the logarithm of the time-dependent density of the stochastic process. This leads to an explicit model for the time-dependent probability distribution, meaning that it is possible to evaluate the probability density, within the time horizon of interest, without path-wise integration of the continuity equation. We use the proposed approach to synthesize new samples of a random vector from a given set of its realizations. We also demonstrate the utility of an explicit approximation to the time-dependent probability density function through applications in unsupervised outlier detection. Additionally, we apply the proposed approach to approximate the time-dependent probability density functions for dynamical systems driven by stochastic excitations. The results show that the proposed method accurately reconstructs complex time-dependent, multi-modal, and near-degenerate densities, scales effectively to moderately high-dimensional problems, and reliably detects rare events within real-world data.

Speaker



Agnimitra Dasgupta

John von Neumann Fellow | Sandia National Laboratories

ID 925: Thermodynamics-Informed Machine Learning for Concrete Fracture Prediction

5:00 PM – 5:20 PM

Author(s): Muhamad Alim, University of California San Diego; Xiaolong He, Synopsis Inc; Jiun Shyan Chen, University of California San Diego

Fracture degrades the performance of reinforced concrete structures by reducing load-carrying capacity. Understanding this fracture behavior is critical for assessing the structural integrity and longevity. Highly time-intensive physics-based simulations for fracture motivate the development of machine-learning-based surrogate model. However, most existing models applied to fracture prediction operate as black boxes and require large training datasets for reliable generalization.

In this work, we propose a thermodynamics-informed ML framework for accurate and efficient concrete fracture prediction. The model integrates a convolutional autoencoder to extract low-dimensional fracture patterns from high-dimensional damage fields and couples it with parametric GENERIC formalism-informed neural networks [1] (ConvAE-pGFINN) that enforce key thermodynamic principles such as total energy conservation and entropy generation.

The proposed model embeds the physics into the neural network architectures using a hard-constraint method that inherently complies with the underlying principles, thereby avoiding the need for physic-based constraint enforcement during the optimization and ensuring the thermodynamically consistent evolution of concrete fracture features. The proposed ConvAE-pGFINN framework is validated by predicting fracture propagation in concrete under various loading magnitudes and reinforcement bar configurations, including variations in rebar layout, diameter, and spacing. A Neural network-enhanced Reproducing Kernel Particle Method (NN-RKPM) is employed to generate 2D and 3D datasets, in which the neural network approximation and background RK approximation are coupled via a partition-of-unity framework [2]. To evaluate the generalization ability of the ConvAE-pGFINN, a purely-data driven Convolutional Neural Network-LSTM (ConvLSTM) model reported in [3] is used as a baseline for comparison. The results show that the proposed ConvAE-pGFINN accurately captures the crack propagation under different loading conditions and reinforcement bar configurations and achieves comparable accuracy with a reduced amount of training data compared to the ConvLSTM. This finding indicates the efficiency of the proposed model in predicting concrete fracture behaviour with limited training data, paving new opportunities for broader implementations in reinforcement bar concrete design and analysis.

Reference

- [1] X.He, Y.Shin, A.Grubler, S.Jung, K.Lee, Y.Choi. Thermodynamically Consistent Latent Dynamics Identification for Parametric Systems. Computer Methods in Applied Mechanics and Engineering. (2024). <https://doi.org/10.48550/arXiv.2506.08475>
- [2] J.Baek, J.S.Chen. A neural network-based enrichment of reproducing kernel approximation for modeling brittle fracture. Computer Methods in Applied Mechanics and Engineering. (2024). <https://doi.org/10.1016/j.cma.2023.116590>
- [3] A.J.Lew, C.H.Yu, Y.C.Hsu, M.J.Buehler. Deep learning model to predict fracture mechanisms of graphene.npj 2D Materials and Applications (2021). <https://doi.org/10.1038/s41699-021-00228-x>

Speaker



Muhamad Alim
UC San Diego

ID 940: A Neural Operator for Homogenization-Based Continuum Models of Granular Materials

5:20 PM – 5:40 PM

Author(s): Bahador Bahmani, Northwestern University

Homogenization-based continuum models provide a computationally efficient framework for simulating granular materials. However, the relationship between microscale constitutive behavior and the resulting macroscopic response is not explicit, making macroscopic control difficult and often reliant on trial-and-error calibration. Moreover, ensuring physically admissible macroscopic behavior may require restrictive assumptions on microscale constitutive laws that are not known a priori. In this work, we introduce a neural operator-based approach that constructs a fully differentiable continuum model for granular materials while enforcing physical admissibility. We further propose an active learning strategy that enables reliable model training with minimal data requirements.

Speaker



Bahador Bahmani
Assistant Professor | Northwestern University

ID 719: A Physics-Based RTM Digital Workflow for Residual-Stress and Cycle-Time-Aware Temperature-Schedule Optimization

5:40 PM – 6:00 PM

Author(s): Samir Saredidine, University of Southern California; Roger Ghanem, University of Southern California

We present an end-to-end, OpenFOAM-based digital workflow for Resin Transfer Molding (RTM) that couples mold filling and post-fill curing with thermo-chemo-rheological physics and process optimization for industrial composite parts. The computational model is implemented in a finite-volume framework and resolves Darcy-driven flow during filling together with energy conservation under porous media assumptions, enabling consistent prediction of temperature evolution throughout injection and subsequent cure. Resin viscosity is modeled using a temperature- and degree-of-cure-dependent Castro–Macosko formulation, while cure kinetics follow a Kamal–Sourour model; both are calibrated against material data to ensure predictive fidelity across the processing window. To demonstrate capability and practical impact, the solver is applied to an industrial tray geometry representative of a curved, plate-like component, where spatially varying thermal histories strongly influence cycle time and defect risk. We formulate a multi-objective optimization problem in which a mold temperature schedule is optimized to reduce manufacturing cycle time while simultaneously mitigating residual-stress development. Residual stresses are estimated through a computationally efficient mechanical surrogate based on plate theory, driven by the simulated thermal and cure histories (activated after gelation), providing a tractable stress/warping proxy suitable for high-throughput design exploration. The optimization is executed using Dakota's evolutionary algorithm, enabling robust search over nonconvex design spaces without requiring gradient information. Results show that time-dependent temperature scheduling can meaningfully shift the trade-off between rapid cure and stress accumulation, highlighting the importance of coupling physics-based RTM simulation with automated optimization. The proposed framework provides a scalable foundation for process design and control of complex composite parts, and it is readily extensible to additional objectives, constraints, and in-mold sensing for future digital-twin applications.

Speaker



Samir Saredidine

PhD student | University of Southern California

MS 011: Advanced Computing for the Resilience of Networked Critical Infrastructure Systems

4:00 PM – 6:00 PM | Location: GUGG 205

Chair(s): Xudong (Andrew) Fan; Teng Wu; Jürgen Hackl; Abdollah Shafieezadeh

Moderators



Xudong Fan

Assistant Professor | University at Buffalo

ID 425: A Decision-Support Framework for Compound Flood-Aware Emergency Vehicle Routing in Urban Networks

4:00 PM – 4:20 PM

Author(s): Gwyneth Nolde, New York University, Tandon School of Engineering, Department of Mechanical and Aerospace Engineering; Joseph Chow, New York University, Tandon School of Engineering, Department of Civil & Urban Engineering; Yuki Miura, New York University, Tandon School of Engineering, Department of Mechanical and Aerospace Engineering

Hurricane Sandy (2012) and Hurricane Ida (2021) demonstrated how dense coastal cities like New York City are susceptible to compound disruptions from flooding and congestion within urban transportation networks, both of which severely constrain emergency service (EMS) mobility. Post-Sandy evaluations suggest that EMS travel time is affected by EMS station closure and is also susceptible to traffic congestion. Though real-time traffic data are already available to anticipate congestion and proactively inform EMS navigation, flood depth information is not available in real-time and simulations have lacked the spatial and temporal resolution required to support routing decisions. However, recent advances in urban flood sensing and simulation now make city-scale flood estimates increasingly feasible, creating a need for routing methods that can exploit this information. This work presents an integrated EMS routing tool that incorporates evolving hazard information and evacuation-driven congestion to support operational decision making during coastal disasters.

The proposed approach couples high-resolution flood simulation with dynamic traffic assignment to produce a time-evolving transportation network state on which EMS routing decisions are made. Coastal storm scenarios are simulated using GeoClaw, Hec-Ras, and GISSR, while evacuation driven-congestion is modeled using macroscopic flow conservation to capture congestion development and propagation across the street network. EMS routes are dynamically evaluated against this shared network representation of realistic and evolving hazard conditions. Uncertainty in driver behaviour and incident occurrence is addressed through repeated stochastic simulations that represent variability in evacuation behaviour and emergency service demand, allowing efficacy of routing policies to be assessed as distributions of outcomes rather than single simulations.

When applied to Sandy, Ida, and synthetic compound flood scenarios in New York City, the results demonstrate how flood-aware routing can affect EMS travel time and incident accessibility. The tool provides a decision support and experimentation platform for evaluating EMS routing strategies under compound hazard and congestion scenarios, and highlights the importance of explicitly incorporating flood dynamics into emergency navigation to enhance the resilience and adaptive capacity of flood-prone transportation systems.

Speaker



Gwyneth Nolde

PhD Student | New York University

ID 530: Topology-Based Community Detection Algorithms for Aggregating Electricity Transmission Networks

4:20 PM – 4:40 PM

Author(s): Megan Thies, Princeton University

Demand for electricity is increasing globally, driven mainly by the electrification of traditionally carbon-intensive resources, increased industrial manufacturing, climate change, and the rise of AI. In order to satisfy this demand increase, new generators must be constructed at the same pace as the demand growth to avoid a supply shortage. In the United States, the interconnection process is one of the barriers to increasing electricity generation. The process is used to analyze potential transmission bottlenecks and calculate transmission interconnection costs for the project. The analysis programs are associated with long run times though because the project's effect is studied across the entire transmission network. One solution is to aggregate groups of nodes into supernodes, run a rough analysis on the aggregated network, then decompose the network into smaller pieces for a refined analysis to be run in parallel. However, the enmeshed structure of the transmission network has made it challenging to determine node groupings that can be run in parallel after decomposition with few enough iterations to decrease the overall run time. Consequently, an active research area includes finding an effective way to group the nodes so that the rough aggregated analysis can be used to inform the refined parallel analysis. Current electricity grid aggregation algorithms use the physics-based constraints or economic/political attributes of the system to group nodes together. In the field of network science, algorithms to group nodes (called community detection) can also be based on the fundamental structure of the network, or its topology. However, there is limited systemic understanding of the utility of topology-based community detection algorithms for electricity grid aggregation.

In this research, several types of community detection algorithms are used to create aggregated forms of standard IEEE test cases. The algorithms are based on modularity maximization, information theory, statistical inference, and betweenness-based methods. The resulting aggregated networks, from each community detection method, are then validated against the original network. The validation is conducted using an Optimal Power Flow (OPF) analysis on the various aggregated and original networks. An OPF analysis is chosen to test the aggregated networks since it is among the more computationally involved analyses needed in electricity planning and operation. The percent difference of each aggregated network against the original network is calculated to demonstrate the accuracy of the OPF results.

Speaker



Megan Thies

Student | Princeton University

ID 604: Reliability of power transmission steel poles under dynamic wind loads

4:40 PM – 5:00 PM

Author(s): Urinrin Otite, Lehigh University; Xinyue Wang, Lehigh University; Sushreyo Misra, Lehigh University; Paolo Bocchini, Lehigh University

Steel transmission monopole towers are increasingly being used to support high-voltage overhead lines, because they reduce right-of-way demands and can be installed and maintained more efficiently than many lattice-tower alternatives. Their structural behavior under hurricane winds is strongly influenced by wind turbulence and by the coupled participation of attached conductors and overhead ground wires. In coastal environments, corrosion-driven section loss near the groundline can further reduce capacity and motivate risk-informed planning for inspection, repair, and replacement. While fragility modeling for power infrastructure has grown substantially, steel monopole tower fragilities that explicitly represent dynamic wind loading and cable-pole interaction remain limited, especially in forms that are directly usable for network-scale resilience assessment.

This work presents a frequency-domain methodology for developing dynamic fragility functions of steel transmission monopoles under hurricane wind excitation, with emphasis on the dynamic response during the most severe period of a storm. Two common configurations are considered representative of single-circuit and double-circuit monopoles. Wind-induced actions on the monopole shaft, conductors, and overhead ground wires are represented through force power spectral densities, including spatial coherence effects that govern correlated turbulence along the height and across line spans. Structural response is computed using modal superposition in the frequency domain, producing response spectra and time-domain exceedance metrics through a first-passage formulation. Non-linear failure is captured by properly setting the limit state for local buckling of the monopole walls. The approach explicitly accounts for the duration of intense winds, so that failure probabilities reflect both wind intensity and exposure time, rather than relying only on peak wind speed. Failure is evaluated for both base and along-height limit states to examine whether higher vibration modes contribute meaningfully to demand not necessarily concentrated near the foundation, and to identify conditions where non-base exceedances may govern. Corrosion effects near the groundline are represented parametrically by reducing section property as a function of age. The primary outputs of this work are dynamic fragility functions for each configuration and limit state, along with quantified influences of storm duration, corrosion severity, and pole age. These results are intended to support network-level outage and restoration modeling, utility asset-management decisions, and catastrophe modeling applications focused on coastal transmission systems.

Speaker



Urinrin Otite

Ph.D. Candidate | Lehigh University

ID 631: Resilience-Oriented Strategic Siting of Solar Farms and Battery Energy Storage System: A Multi-Stage Stochastic Robust Optimization Approach

5:00 PM – 5:20 PM

Author(s): Jaeyeong Lim, The Ohio State University; Abdollah Shafieezadeh, The Ohio State University

The strategic placement of Solar Farms and Battery Energy Storage Systems (BESS) is a determining factor in enhancing the resilience of distribution networks against extreme weather events. However, conventional siting methodologies frequently overlook the interdependence between physical asset fragility and the complex, multi-stage operational dynamics of disaster response. To overcome these limitations, this study proposes a novel resilience-oriented siting framework formulated as a multi-stage, bi-level Stochastic Robust Optimization (SRO) problem. Uniquely, this framework co-optimizes the location and sizing of renewable assets with a complete hazard timeline—encompassing pre-event investment, worst-case damage realization constrained by an information-theoretic uncertainty budget, autonomous self-healing via reconfiguration, and coordinated crew restoration. A critical innovation is the direct integration of probabilistic structural fragility models for both grid infrastructure and renewable components into the siting optimization, ensuring that deployed assets are physically robust to hazard-induced failures. To guarantee computational tractability, the nested bi-level problem is reformulated into a single-level Mixed-Integer Linear Programming (MILP) model, with strategic placement decisions solved via a Differential Evolution algorithm. Numerical validations on IEEE 33- and 118-bus systems demonstrate that this holistic siting strategy yields substantial improvements in system resilience and significant reductions in total hazard-related costs compared to traditional baselines. Furthermore, a 25-year life-cycle cost-benefit analysis confirms the long-term economic viability and cost-effectiveness of these resilience-driven investments.

Speaker



Jaeyeong Lim

PHD Candidate | The Ohio State University

ID 936: Adaptation Planning for Interconnected Coastal Infrastructure Systems

5:20 PM – 5:40 PM

Author(s): Aditya Sharma, The Pennsylvania State University; Ashmita Bhattacharya, The Pennsylvania State University; Kostas G. Papakonstantinou, The Pennsylvania State University; Gordon P. Warn, The Pennsylvania State University

Infrastructure adaptation planning for climate change effects requires methodologies that can optimize long-term life-cycle costs within urban systems that are interconnected and subject to substantial uncertainties. Advances in dynamic decision-making frameworks have enabled planning that can suggest adaptation actions over time, generally outperforming typical static, risk-based strategies by incorporating evolving information on climate risks and uncertainties. While such dynamic approaches can more effectively address uncertainties within adaptation planning, most existing formulations have been demonstrated at the level of individual assets or regions, which might not necessarily translate to optimal system planning when considering the inherent interactions and inter-regional dependencies that characterize interconnected urban areas. As such, this work presents a methodology for the optimal life-cycle adaptation of coastal infrastructure systems, considering urban environments as networked systems rather than isolated regions. Within this system modeling perspective, socio-economic as well as infrastructure couplings are explicitly embedded through a system-wide loss model, capturing inter-regional dependencies and the propagation of indirect impacts. Climate risk management is then formulated as a Markov Decision Process (MDP), as it has been shown[1] to be able to identify time-dependent adaptation actions based on the actual evolving climate conditions, while accounting for uncertainties and non-stationarities, and, importantly, providing global optimality guarantees for the resulting problem formulation. The derived methodology is demonstrated through a New York City metropolitan area inspired case study comprising five interconnected coastal regions, where, beyond direct flood losses, inter-regional economic dependencies and transit-related disruptions inform direct and indirect system-wide losses. A diverse set of actions is considered in this study, including grey- as well as nature-based solutions. Related environmental impacts of carbon emissions and uptake are also incorporated using the notion of the social cost of carbon. Results confirm that by dynamically adjusting adaptation actions in response to the evolving climate, MDP-based policies outperform conventional static and condition-based decision strategies. Finally, the importance of considering interdependencies and connectivities across regions is also highlighted.

[1] Bhattacharya, Ashmita, Konstantinos G. Papakonstantinou, Gordon P. Warn, Lauren McPhillips, Melissa M. Bilec, Chris E. Forest, Rahaf Hasan, and Digant Chavda. "Optimal life-cycle adaptation of coastal infrastructure under climate change." *Nature Communications* 16, no. 1 (2025): 1076. <https://doi.org/10.1038/s41467-024-55679-9>

Speaker



Aditya Sharma

PhD Candidate | The Pennsylvania State University

ID 1000: Resilience Assessment and Enhancement of Interdependent Power-Transportation Systems Under Ice Storms

5:40 PM – 6:00 PM

Author(s): Safal Pathak, Rensselaer Polytechnic Institute; Guangyang Hou, Exponent, Inc.; Min Li, Rensselaer Polytechnic Institute

Abstract

Prolonged ice storms can disrupt critical infrastructure systems, leading to significant economic and societal losses. Climate change projections indicate these events may increase in frequency and severity, making resilience enhancement increasingly critical. These storms often simultaneously degrade power distribution systems (PDS) and transportation systems (TS), whose performance and recovery are interdependent through traffic-signal outages, roadway blockages, and repair-crew accessibility. Most existing studies assess these systems in isolation, failing to capture how their bidirectional dependencies intensify disaster impacts and impede recovery. To address this gap, this study develops a comprehensive probabilistic framework to assess and enhance the resilience of interdependent PDS-TS networks under ice storms. The framework incorporates an empirical tree-fragility model and multidimensional fragility functions for PDS components (poles and wires), derived from finite-element analyses. It explicitly models three critical bidirectional interdependencies: (i) traffic signal functionality dependent on PDS operation, (ii) roadway traffic flow dependent on roadside power poles integrity, and (iii) PDS restoration efficiency dependent on repair-crew travel time on the TS. System performance is quantified using connectivity-based metrics for PDS (the ratio of customers with power) and flow-based metrics for TS (incorporating traffic delays from signal outages and capacity reductions due to roadway blockages). Resilience is evaluated using time-integrated performance indices. On this basis, resilience enhancement is formulated using a Resilience Achievement Worth (RAW) metric that quantifies the relative contribution of individual components to the joint PDS-TS resilience objectives. The RAW metric is used to prioritize, under realistic restoration resource constraints, three resilience enhancement strategies: upgrades to poles, vegetation management, and backup power installations for critical traffic signals to improve system resilience. To demonstrate the effectiveness of the proposed framework, it is applied to a PDS-TS network in Oklahoma.

Keywords: Ice storm; resilience; power distribution systems; transportation systems; service restoration.

Speaker



Safal Pathak

Graduate Research Assistant | Rensselaer Polytechnic Institute

MS 081: Computational Methods for Stochastic Engineering Dynamics

4:00 PM – 6:00 PM | Location: ECON 119

Chair(s): Ketson dos Santos; Vasileios Fragkoulis; Ioannis Kougioumtzoglou; Antonina Pirrota; Athanasios Pantelous

Moderators



Ketson dos Santos

Prof. | University of Minnesota

ID 210: Operatorial Stochastic Dynamics for Efficient Time-Dependent Uncertainty Propagation and Reliability Analysis in Nonlinear Systems

4:00 PM – 4:20 PM

Author(s): João Gabriel Duarte, University of Minnesota; Ketson dos Santos, University of Minnesota

The development of methods that enable the efficient quantification of uncertainty propagation through complex, nonlinear, and potentially time-variant differential equations governing the dynamics of engineering systems subjected to random excitation is of fundamental importance for probabilistic analyses across multiple scales, including micro-electro-mechanical resonators, vibratory energy harvesters, and high-rise buildings. However, achieving high accuracy in the probabilistic response requires technically consistent approaches grounded in solid mathematical theory. To this end, this work introduces the concept of linear operator theory in the development of a methodology, referred to as Operatorial Stochastic Dynamics (OSD), aimed at the computationally efficient determination of the time-dependent probability density function (PDF) and survival probability of nonlinear oscillators. Specifically, the system state space is modeled as a Markov process, enabling the discretization of a stochastic Liouvillian whose affine decomposition permits the construction of a time-dependent generator defined by: (i) the forward action of the Liouvillian, corresponding to the Fokker–Planck–Kolmogorov operator governing the time evolution of the state-space PDF; and (ii) its adjoint, associated with the backward Kolmogorov operator, which yields the backward-in-time evolution of survival-related observables. By employing a matrix-exponential time-evolution operator, the OSD framework achieves unconditionally stable propagation of both the joint stochastic response and the survival probability. Illustrative examples are presented to validate the proposed methodology and to assess its computational performance.

Speaker



Joao Gabriel Duarte

Ph.D. Candidate | University of Minnesota

ID 251: Efficient stochastic response determination of nonlinear systems with singular matrices via a reduced-order formulation of the Wiener path integral technique

4:20 PM – 4:40 PM

Author(s): Miao Liu, University of Minnesota; Ketson dos Santos, University of Minnesota; Ioannis Kougiumtzoglou, Columbia University

The Wiener path integral (WPI) technique for determining the stochastic response of diverse nonlinear dynamical systems relates to treating the system response joint transition probability density function (PDF) as a functional integral over the space of all possible paths connecting the initial and the final states of the response vector [1]. Further, the functional integral is evaluated, ordinarily, by resorting to an approximate approach that considers the contribution only of the most probable path. This corresponds to an extremum of the functional integrand and is determined by solving a functional minimization problem that takes the form of a deterministic boundary value problem (BVP). Recently, to increase the computational efficiency associated with the WPI technique, a reduced-order WPI variational formulation was developed in [2]. This reduced-order formulation can be construed as an efficient dimension reduction approach that renders the associated computational cost independent of the total number of degrees-of-freedom (DOF) of the system. Concisely stated, the technique can determine directly any lower-dimensional joint response PDF corresponding to a subset only of the response vector components by utilizing an appropriate combination of fixed and free boundary conditions. In this paper, the technique in [2] is extended based on a constrained variational formulation [3] to treat a broader class of systems whose governing equations are characterized by singular diffusion matrices. Representative examples include nonlinear systems exhibiting hysteresis modeled by additional auxiliary state equations (e.g., Bouc-Wen formalism), structures with only a subset of their degrees-of-freedom excited, and energy harvesters with coupled electro-mechanical equations.

[1] Kougiumtzoglou I. A., Psaros A. F., Spanos P. D., 2024. Path Integrals in Stochastic Engineering Dynamics, Springer, ISBN 978-3-031-57862-5, <https://doi.org/10.1007/978-3-031-57863-2>.

[2] Petromichelakis I., Kougiumtzoglou I. A., 2020. Addressing the curse of dimensionality in stochastic dynamics: A Wiener path integral variational formulation with free boundaries, Proceedings of the Royal Society A, vol. 476: 20200385.

[3] Petromichelakis I., Psaros, A. F., Kougiumtzoglou I. A., 2020. Stochastic response determination of nonlinear structural systems with singular diffusion matrices: A Wiener path integral variational formulation with constraints, Probabilistic Engineering Mechanics, vol. 60: 103044.

Speaker



Miao Liu

Ph.D student | University of Minnesota

ID 264: Efficient Uncertainty Propagation in Nonlinear Dynamical Systems Using Fourier Transform and Semi-Lagrangian Remapping: An Operatorial Dynamics Approach

4:40 PM – 5:00 PM

Author(s): Ketson dos Santos, University of Minnesota; Miao Liu, University of Minnesota; João Gabriel Duarte, University of Minnesota

The computational burden of performing uncertainty propagation analysis in systems modeled by complex nonlinear differential equations hinders the development of numerical techniques for accurate reliability analyses and efficient optimization under uncertainties in diverse engineering systems. It is evident that circumventing this computational limitation is key for the accurate probabilistic assessment of nonlinear systems under uncertainties; therefore, this paper presents a methodology based on the theory of linear operators to enable quick probabilistic response estimation of oscillators with nonlinear stiffness terms. The method is constructed using the concept of spectral decomposition of the Liouville operator for conservative dynamics and is extended to the analysis of systems subjected to white-noise excitation. To this end, the system response is modeled as a Markovian process with evolution of the density over the state space governed by the Fokker–Planck (FP) equation, which enables the decomposition of the FP operator into advection and diffusion components, allowing the appropriate combination of Fourier transforms and semi-Lagrangian remapping for constructing an intuitive scheme for probability transport. To validate the efficiency and accuracy of this method, a strongly nonlinear oscillator is included as an indicative example, where the obtained system-response probability density functions (PDFs) are properly compared with empirical PDFs estimated from Monte Carlo simulations.

Speaker



Ketson dos Santos

Prof. | University of Minnesota

ID 364: An enhanced extrapolation approach within the Wiener path integral technique for stochastic response determination of high-dimensional systems

5:00 PM – 5:20 PM

Author(s): Ilias Mavromatis, Columbia University; Ketson dos Santos, University of Minnesota; Ioannis Kougiumtzoglou, Columbia University

The Wiener path integral (WPI) technique for determining the stochastic response of diverse nonlinear dynamical systems treats the system response joint transition probability density function (PDF) as a functional integral over the space of all possible paths connecting the initial and the final states of the response vector [1]. Further, the functional integral is evaluated, ordinarily, by considering the contribution only of the most probable path. This corresponds to an extremum of the functional integrand, and is determined by solving a functional minimization problem that takes the form of a deterministic boundary value problem (BVP). Recently, an extrapolation approach within the WPI technique was developed that reduces the computational cost by several orders of magnitude [2]. This was done by utilizing information embedded in the time-history of the most probable path, and by exploiting the fact that the BVP corresponding to two neighboring points in the response PDF domain not only share the same equations, but also the respective boundary conditions differ only slightly. In this paper, the extrapolation technique is further enhanced based on an efficient reduced-order variational formulation that renders the associated computational cost independent of the total number of degrees-of-freedom (DOF) of the system, thereby circumventing the curse of dimensionality and enabling the stochastic analysis of truly high-dimensional systems.

[1] Kougiumtzoglou I. A., Psaros A. F., Spanos P. D., 2024. Path Integrals in Stochastic Engineering Dynamics, Springer, ISBN 978-3-031-57862-5, <https://doi.org/10.1007/978-3-031-57863-2>.

[2] Mavromatis, I. G., Kougiumtzoglou, I. A., Spanos, P. D., 2024. An extrapolation approach within the Wiener path integral technique for efficient stochastic response determination of nonlinear systems. International Journal of Non-Linear Mechanics, 160, 104646.

Speaker



Ioannis Kougiumtzoglou

Associate Professor | Columbia University

ID 852: A GPCE-NARX Framework for Uncertainty Quantification in Dynamical Systems in the Presence of Dependent Random Variables

5:20 PM – 5:40 PM

Author(s): Mohammadamin Ebadollahi, The University of Iowa; Sharif Rahman, The University of Iowa

This paper puts forward a solid theoretical foundation, accompanied by robust numerical algorithms and computational tools, for time-dependent uncertainty quantification (UQ) analysis of dynamical systems subject to random input with dependent probability distributions. The method of analysis involves (1) a stochastic adaptation of Nonlinear AutoRegressive with eXogenous input (NARX) model to effectively capture the dynamic behavior of a general complex system [1]; (2) a generalized polynomial chaos expansion (GPCE) to propagate the statistically dependent input uncertainty to the NARX coefficients [2]; and (3) an innovative GPCE-NARX fusion for estimating the statistical moments and probability density function of a stochastic dynamic response of interest. Compared with past works [3], the GPCE-NARX framework proposed can handle arbitrary, dependent probability distributions of random input, heretofore unavailable to the scientific community. By decoupling the temporal dynamics through NARX and managing time-independent stochastic complexity via GPCE, the framework judiciously overcomes the longstanding challenges of long-time integration that have historically constrained the effectiveness of existing UQ methods. The numerical results demonstrate that a low-order GPCE-NARX approximation yields accurate estimates of the probabilistic characteristics of simple dynamical systems while maintaining high computational efficiency. Furthermore, the probabilistic analysis of an engineering system highlights the capability of the GPCE-NARX method to effectively address complex UQ problems in the field of Dynamics.

[1] Billings, S. A., Nonlinear System Identification: NARMAX methods in the Time, Frequency, and Spatio-Temporal Domains, John Wiley & Sons, 2013.

[2] Rahman, S., "A Polynomial Chaos Expansion in Dependent Random Variables," Journal of Mathematical Analysis and Applications, Vol. 464, pp. 749-775, 2018.

[3] Ebadollahi, M. and Rahman, S., "Time-dependent Uncertainty Quantification Analysis of Complex Dynamical Systems," Probabilistic Engineering Mechanics, Vol. 80, Article 103776, pp. 1-19, 2025.

Speaker



Amin Ebadollahi

Research assistant | The University of Iowa

ID 857: Thermodynamic Framework for Collective Dynamics in Large-Scale Nonlinear Structural Systems

5:40 PM – 6:00 PM

Author(s): Ahyeon Seo, Seoul National University; Heedong Goh, Seoul National University

The global response of a structural system is often approximated as a superposition of individual responses of buildings as nonlinear oscillators. This assumption fails, however, when each building is weakly but non-negligibly coupled to its neighbors. Such systems exhibit emergent city-scale dynamics irreducible to linear superposition, e.g., the town effect, in which thousands of oscillators undergo collective frequency shifts [1], and long-range phase ordering analogous to coupled spin fields [2]. These phenomena suggest latent degrees of freedom that evolve slowly yet coherently, modulating the power spectra of individual oscillators—motivating a reduced description at the envelope level. Unlike direct numerical simulation, which becomes intractable for large systems, envelope-based analysis remains computationally feasible. In non-integrable systems of this scale, nonlinear energy transfer occurs through innumerable interaction channels, rendering microscopic pathways opaque. By contrast, the reduced description enables an explicit derivation of the modal energy distribution. Based on this distribution, we formulate a consistent thermodynamic framework for collective behavior, parameterized by macroscopic state variables such as an effective temperature defined by mechanical parameters. The reduction proceeds by averaging out fast linear oscillations, eliminating rapid components and second-order derivatives to obtain envelope equations parameterized by mechanical quantities. The resulting dynamics approximate an ergodic system with a generalized free energy. In the Fourier domain under a continuum approximation, nonlinear terms capture the cumulative effect of infinitely many resonant channels. On slow time scales, Fourier coefficients evolve as effective stochastic processes [3], and the stationary mean modal energy converges to a Rayleigh–Jeans distribution with negligible fluctuations.

This framework establishes a direct analogy to Boltzmann statistical thermodynamics. The effective temperature emerges from the modal energy distribution and depends solely on mechanical parameters, thereby connecting microscopic system properties to macroscopic observables. This connection enables practical prediction and control of collective phenomena, including phase transitions in distance-dependent correlations.

[1] Uenishi, K. (2010). The town effect: dynamic interaction between a group of structures and waves in the ground. *Rock mechanics and rock engineering*, 43(6), 811-819.

[2] Oh, S., Yi, S., & Wang, Z. (2024). Long-range Ising model for regional-scale seismic risk analysis. *Earthquake Engineering & Structural Dynamics*, 53(12), 3904-3923.

[3] Chibbaro, S., Dematteis, G., & Rondoni, L. (2018). 4-wave dynamics in kinetic wave turbulence. *Physica D: Nonlinear Phenomena*, 362, 24-59.

Speaker



Ahyeon Seo

Ms. | Seoul National University

MS 076: Advances in Modeling Wind and Its Effects on the Built Environment

4:00 PM – 6:00 PM | Location: CHEM 140

Chair(s): Teng Wu; Catherine Gorle; Marco Giometto

Moderators



Teng Wu

Prof. | University at Buffalo

ID 656: Performance-Based Wind Assessment of Two-Way Coupled Structural–Envelope Systems under Extreme Winds

4:00 PM – 4:20 PM

Author(s): Jieling Jiang, University of Michigan; Seymour Spence, University of Michigan

Performance-based wind design has gained increasing attention over recent decades, driven by a shift toward the explicit evaluation of building performance across a broad range of wind intensities. Documented losses of building envelope systems under extreme wind events have highlighted the critical role of envelope performance in overall structural resilience. However, most existing performance-based assessments assume that, while external pressures may damage envelope components, such failures do not influence subsequent wind loading. As a result, the pressure redistribution associated with dynamic envelope loss remains insufficiently explored. To address this gap, this study develops a computational framework to capture and quantify the influence of dynamic envelope loss on internal and external dynamic wind pressures. Unsteady Reynolds-averaged Navier–Stokes (URANS) simulations are conducted to resolve the evolving wind field and are coupled in real time with envelope damage represented through component-level fragility models. Dynamic openings and background leakage are explicitly modeled when the evolving net pressures exceed component-specific failure thresholds sampled from the fragility functions. A two-story building is employed as a case study to demonstrate the proposed framework. Statistical characteristics of the wind loads and the resulting building and envelope damage under varying wind intensities are analyzed and compared to identify regimes in which two-way coupling between envelope failure and aerodynamic loading becomes critical.

Speaker



Jieling Jiang

University of Michigan

ID 933: AI-Empowered Structural Optimization and Control in a Wind Tunnel

4:20 PM – 4:40 PM

Author(s): Zhehong Zhang, The State University of New York at Buffalo; Teng Wu, The State University of New York at Buffalo; Andrew Whittaker, The State University of New York at Buffalo; Scot Weinreber, The State University of New York at Buffalo

Wind tunnel testing remains the most reliable approach for characterizing and quantifying structural aerodynamics and aeroelasticity. However, wind tunnel tests are typically employed for final design validation rather than for structural design optimization. A major challenge is that structural models used for wind tunnel testing do not allow for speedy changes/modifications of design parameters to efficiently explore optimal structural dynamics (i.e., mass, damping, and stiffness) and aerodynamics (i.e., geometry). If wind mitigation strategies are needed after structural optimization, current testing techniques do not support effective identification of control protocols for smart structures equipped with active devices or morphing appendages. The major challenge is that the used control algorithms cannot learn directly from physical wind environments for efficient exploration of optimal actions. To address these two challenges, this study develops a new wind tunnel testing platform featuring an adaptive structural system (with continuously tunable aerodynamic geometry and structural dynamics) and a model-free nonlinear controller (with autolearning capability without human intervention). Specifically for facilitating structural aerodynamics optimization, an adaptive skin system is developed, with key shape parameters identified through geometric parameterization and the corresponding actuation locations driven by an integrated actuator–transmission mechanism. To facilitate structural dynamics optimization, an adaptive skeleton system is realized through real-time aerodynamics hybrid simulation, with the dynamic properties numerically simulated using computational structural dynamics and the corresponding structural motion under aerodynamic loads driven by a network of physical actuators. For the purpose of efficient iteration during the structural optimization, both geometric parameterization for structural aerodynamics and numerical simulation for structural dynamics are accelerated through deep supervised learning. To enable effective structural control, deep reinforcement learning is integrated into the wind tunnel control loop, enabling data-driven discovery of optimal control policies under realistic wind conditions, with measured aerodynamic loads and/or structural responses used as performance-based rewards. This AI-empowered platform is implemented on the University at Buffalo (UB) multiple-fan wind tunnel with a tall building model (for structural optimization demonstration) and a sectional bridge model (for structural control demonstration). The successful implementation of the proposed AI-empowered structural optimization and control platform should enable a paradigm shift toward an autonomous wind tunnel testing.

Speaker



Zhang Zhehong

Mr. | SUNY UNIVERSITY AT BUFFALO

ID 583: Weak signal extraction enabled by deep neural network denoising of multi-hole velocity probe data for boundary layer wind tunnel applications

4:40 PM – 5:00 PM

Author(s): Ryan Catarelli, University of Florida; Brian Phillips, University of Florida; Tai-An Chen, University of Florida; Jennifer Bridge, University of Florida; Kurtis Gurley, University of Florida

This work presents the development and implementation of a frequency domain deep neural network (DNN) denoising filter for weak signals measured by multi-hole velocity probes. These probes are used on a recently commissioned automated multi-degree of freedom (MDOF) instrument traverse in a large boundary layer wind tunnel (BLWT) designed and fabricated at the University of Florida (UF) Experimental Facility within the NSF Natural Hazards Engineering Research Infrastructure (NHERI) program. The goal is to improve the measurement performance of a class of multi-hole velocity probes that are traditionally considered slow- to intermediate-response sensors used in low-speed wind tunnels, where differential pressure transducer loading is minimal in the high-frequency range and long tubing often connects the measurement location to the transduction location.

Velocity measurements in the UF BLWT are collected using 12 vertically spaced five-hole Vectroflow intermediate-response (i.e., 0-400 Hz) velocity probes. This configuration enables time synchronous measurements of the entire rough wall turbulent boundary layer extending from the floor to freestream (~1.60 m) with acceptable spatial resolution. The pressure signals present at the probe tips travel in 1.65 m long tubing to a 64-channel Scanivalve MPS 4264 pressure scanner, where the raw measured pressures are corrected using analytical tubing response transfer functions. An equivalent fast-response velocity probe system would be over three times the cost, which is prohibitively expensive and is the primary motivation for this work.

The physical tubing geometry of the velocity measurement system causes the higher frequency range of the measured signals, particularly at low speeds, to become so attenuated that they are difficult to discern from sensor noise at the point of transduction in the pressure scanner even after the tubing response transfer functions are applied to correct the data. However, we demonstrate that weak signals stemming from the tubing attenuation, insignificant in the raw noisy data, become visible and accurate in the denoised data. This success is enabled by supervised training of a DNN with pairs of measured low- and high-noise data captured using two different types of multi-hole velocity probes, a fast-response TFI Cobra Velocity Probe and the Vectroflow velocity probe to be used in operation. The full set of 926 training data pairs were generated in stationary flow conditions in the UF BLWT for the full range of mean velocity, turbulence intensity, and integral length scale combinations achievable using an active-passive turbulence modulation system previously developed. This method may be generally applied to increase the capability of intermediate-response probes to resolve weak signals at higher frequencies, which were traditionally only measurable using the more expensive fast-response velocity probes.

Speaker



Ryan Catarelli

Research Assistant Scientist | University of Florida

ID 435 Experimental Study of Windborne Debris Flight in Turbulent Flows

5:00 PM – 5:20 PM

Author(s): Kimia Yousefi Anarak, Colorado State University; Shaopeng Li, University of Louisiana at Lafayette; Ryan Catarelli, University of Florida; Yanlin Guo, Colorado State University; Kurtis Gurley, University of Florida; John van de Lindt, Colorado State University

Windborne debris poses significant hazards to building exteriors in urban environments. Experimental investigations of debris flight under realistic turbulent wind conditions remain limited, particularly those incorporating highly turbulent inflow profiles, entire frequency spectrum of velocity at inflow, building induced wake flows, and properly scaled debris and wind flow characteristics. To understand the risks of buildings under windborne debris hazards, this study experimentally compares the flight statistics of windborne debris in turbulent wind fields with incremental complexities. The debris is released to wind flow using a customized release mechanism. Three debris release scenarios are examined: (1) debris released into open flow, (2) debris released into the wind flow interfered by a neighboring building, and (3) debris released into wind flow from the roof of a source building (at the most critical location for rooftop gravel scouring) with the same dimension as the neighboring building in Scenario 2. The building models have a geometric proportion of 1:1:2 (B:D:H), with dimensions of 0.5 m×0.5 m×1 m. The debris is released at 1 m height in scenarios. Previous rooftop surface scouring tests under identical inflow conditions indicate that a 45° orientation leads to the most severe rooftop scouring; therefore, this orientation is used for Scenario 3 and, for consistency, is also adopted for Scenario 2. A relatively large length scale of 1:20 is employed to ensure reliable tracking of small debris particles (1.5 mm) within the wind tunnel environment. Debris trajectories are captured using a stereo vision system, and the recorded images are post-processed to obtain the three-dimensional debris locations throughout the flight. For all three scenarios, an identical boundary layer wind profile is generated by actively controlled fans with a high turbulence intensity of approximately 23.7% at 1 m height and used as the inflow condition. The resulting data enables a comparative evaluation of debris flight statistics across varying levels of wind field complexity at the debris release location, providing insights relevant to windborne debris risk in urban settings.

Speakers



Kimia Yousefi Anarak
Colorado State University



Yanlin Guo
Associate Professor | Colorado State University

MS 088: Advances in Damage Mechanics and Micromechanics - in Honor of the 2025 Blaise Pascal Medal in Engineering to Professor Jiann-Wen Woody Ju

4:00 PM – 6:00 PM | Location: UMC 247

Chair(s): Huiming Yin; Lizhi Sun; Glaucio Paulino; Yong-Rak Kim

Moderators



Lizhi Sun
Professor | UC Irvine

ID 952: Investigating delamination in thermo-oxidatively aged thermoplastic carbon fiber composites

4:00 PM – 4:20 PM

Author(s): Carson Mead, University of Colorado Boulder; Santiago Marin, University of Colorado Boulder; Maryam Shakiba, University of Colorado Boulder

In this work, we characterize and model the effects of thermal-oxidative aging on the mechanical response of a thermoplastic carbon fiber composite. Thermoplastic polymer composites (TPCs), more specifically carbon fiber reinforced thermoplastic carbon fiber composites, have recently become staples in the aerospace, automotive, and defense industries. This is due to their promising properties when compared to thermoset polymer composites including high toughness, recyclability, weldability, improved impact resistance, lower density, and the prospect of out-of-autoclave manufacturing. Rapid out-of-autoclave manufacturing via in-situ consolidation of automated fiber placement of thermoplastics (ICAT) offers the potential for a considerable increase in industry manufacturing speeds. Extreme environmental conditions associated with industrial applications can lead to temperatures that exceed the thermoplastic matrix's low glass transition temperature required for optimal ICAT performance. Current literature has delved into the effects of ICAT manufacturing parameters on TPC mechanical response; however, the effects of extreme environments on composites produced by this relatively recent manufacturing process remain unexplored.

This study investigates the effect of extended exposure to temperatures above the polymer's glass transition temperature on the mechanical response of TPCs. The TPC analyzed in this work is a low melting point quasi-isotropic carbon fiber composite composed of 24 plies in the [45/90/-45/0]3S stacking sequence. The mechanical behavior is studied through four-point bending and short beam strength tests to capture a variety of mechanical behaviors. The four-point bending test exhibited limited sensitivity to aging effects because failure was governed by fiber-dominated compressive bending followed by delamination. The short beam strength test displayed shear-dominated behavior as it isolated the matrix and interlaminar bonding—portions of the composite most easily affected by the aging process. The composite mechanical response was further investigated using analytical and finite element models to predict the degradation response of the thermoplastic composite. The finite element framework captures both damage evolution in composite plies and interlaminar damage through a cohesive zone model.

Speaker



Carson Mead
Mr. | University of Colorado Boulder

ID 966: Homogenization of a lattice network from flow prediction to traffic routing

4:20 PM – 4:40 PM

Author(s): Angelina Shen, Columbia

Flow through two-dimensional physical networks is a universal phenomenon observed in electric grids, transportation systems, water distribution networks, and data infrastructures. In such networks, flow remains constant along each link and is conserved at every node; however, local damage, degradation, or capacity reduction can strongly alter global flow patterns. Traditional graph-theoretic approaches model these effects discretely but often suffer from high computational complexity when applied to large-scale or damaged networks. In this work, we homogenize a physical network into a two-dimensional continuum, allowing network flow to be described by a potential field governed by a boundary value problem. Local damage or congestion is naturally incorporated through spatially varying conductivity fields, enabling efficient representation of micromechanical disruptions at the macroscopic scale. The singum model provides a systematic transformation from a discrete network to a continuum formulation, with computational complexity that can be tailored to available resources. This continuum framework enables rapid evaluation of flow redistribution under damage scenarios and supports applications in infrastructure resilience, disaster evacuation routing, traffic prediction, and network planning and optimization. In particular, evacuation routing under disrupted roadway conditions is demonstrated as a representative application, illustrating how damaged regions deflect flow paths and alter optimal routes within the homogenized potential field. The proposed singum-based homogenization is general and can be extended to other lattice metamaterials for effective mechanical properties with force transfer.

Speaker



Angelina Shen

Miss | Columbia University

ID 969: Effective Elasticity of Miura-Ori–Based Lattices by Singular Continuum (Singum) Homogenization

4:40 PM – 5:00 PM

Author(s): Chao liu, columbia university; huiming yin, columbia university; Glaucio Paulino, Princeton University

Origami-inspired truss lattices exhibit large, programmable kinematics, and their overall elasticity is enigmatic due to the strong configuration dependence and zero-energy mobility. This work develops a closed-form homogenization framework by introducing a “singular continuum” description: in which each node is represented by its Wigner–Seitz cell and treated as a continuum particle, namely “singum” which fills the space periodically and continuously. When multiple-layers of Miura-ori sheets stack together, a three-dimensional (3D) lattice can represent the structure. Considering equilibrium and compatibility at the unit-cell level, we derive an explicit effective elasticity tensor on the current configuration. The model captures the coexistence of zero-energy folding modes by neglecting rotational stiffness and sensible elasticity of other deformation modes in terms of the incremental Cauchy stress by an incremental displacement gradient. Numerical simulations of large periodic lattices under displacement-controlled loading validate the analytical predictions. The effective elastic moduli vary remarkably with prestress and folding state, producing pronounced tunable anisotropy and, under prestress, loss of classical stiffness symmetries: Therefore, asymmetric stress/strain measures are used to describe the response which provides stability criteria and identifies the onset of zero-energy modes by eigen-analysis of the stiffness tensor. The proposed singum-based approach is general and can be extended to other lattice metamaterials with confined force networks and configuration-dependent elasticity.

Keywords: Origami, homogenization, singum, prestress-dependent stiffness, anisotropic elasticity

Speaker



Chao Liu

Mr. | columbia university

ID 971: Multiphysics Characterization of Microfiber-reinforced Bentonite for Deep Geological Repositories

5:00 PM – 5:20 PM

Author(s): Abdullah Azzam, Texas A&M University; Mohammad Rahmani, Texas A&M University; Yong-Rak Kim, Texas A&M University; Jongwan Eun, University of Maryland; Seunghee Kim, University of Nebraska-Lincoln

Geological repositories represent the leading long-term solution for nuclear waste disposal, relying on an engineered barrier system (EBS) to encapsulate waste canisters. Bentonite clay is the preferred barrier material due to its low permeability and long-term stability. However, its performance is compromised by complex thermo-hydro-mechanical (THM) conditions; heat from the waste induces desiccation cracking, while moisture from the host rock causes swelling, potentially creating preferential flow paths that reduce containment efficiency. To address this challenge, we propose and investigate a novel inorganic microfiber-reinforced engineered barrier material (IMEBM) designed for enhanced resistance to desiccation cracking. This study integrates laboratory experiments with multiphysics computational modeling to characterize the IMEBM's performance. The experimental program includes: (1) a restrained ring test to quantify desiccation cracking using digital image correlation (DIC), and (2) a 3D soil tube test to investigate coupled heat and moisture transport. These tests were simulated using a multiphysical finite element (FE) model to calibrate moisture- and temperature-dependent material properties. Analysis of the resulting data—including deformation maps, 3D X-ray CT images, and temperature/moisture profiles—demonstrates the significant role of inorganic microfibers in mitigating cracking, validating the potential of IMEBMs as a promising barrier material for geological repositories.

Speaker



Yong-Rak Kim

Professor | Texas A&M University

ID 996: Damage mechanics of hafnia–silica nanolaminate coatings under extreme conditions

5:20 PM – 5:40 PM

Author(s): Fariha Haque, The Ohio State University; Alok Sutradhar, The Ohio State University

Ultrafast laser irradiation of layered solids induces extreme, highly transient stress fields capable of activating interfacial fracture, delamination, and blistering prior to bulk material failure. In this work, we develop a mechanistic, simulation-based framework to investigate damage evolution in hafnia–silica nanolaminate coatings subjected to femtosecond laser–induced impulsive loading. A cohesive zone–based fracture formulation is employed to capture the initiation, propagation, and interaction of interfacial cracks driven by localized, ultrafast thermo-mechanical stresses. The simulations elucidate how nanoscale layer thickness, elastic mismatch, and interfacial strength and toughness govern damage pathways, delamination morphology, and the emergence of blistering instabilities. These results demonstrate that deliberate interface engineering in nanolaminate architectures provides an effective damage-mitigation strategy under extreme, non-equilibrium loading conditions and offer broader insights into the damage mechanics of layered materials subjected to ultrafast energy deposition.

Speaker



Fariha Haque

Ms | The Ohio State University

ID 1021: Regularization-free 3D Ductile Fracture Simulation using Gurson-Cohesive Modeling (GCM)

5:40 PM – 6:00 PM

Author(s): Kyoungsoo Park, Department of Civil & Environmental Engineering, Yonsei University, Seoul, S. Korea; Jihyuk Park, Yonsei University, Seoul, S. Korea and Southern Illinois University, Edwardsville, USA; Soondo Kweon, University of Illinois at Urbana-Champaign, Urbana, USA; Siwoo Jeon, Yonsei University, Seoul, S. Korea

For ductile fracture simulation, continuum damage-based models have been widely utilized while introducing a regularization process in conjunction with a length scale parameter. One should note that several regularization processes are available to reduce an element size dependency. To avoid the element size dependency and the regularization process, a simple continuum damage model and a discrete fracture model are integrated to investigate ductile fracture phenomena associated with void growth and coalescences, micro-crack initiation, softening, and complete failure [1]. The Gurson model [2] is employed to describe continuum damage, while the Park-Paulino-Roesler (PPR) model [3] is utilized to characterize softening and complete failure. The transition from the continuum damage to discrete fracture is defined based on a porosity-based micro-crack initiation criterion in relation with a stress-triaxiality. The computational results of GCM demonstrates the convergence of local and global responses under mesh refinement without a regularization process. Furthermore, GCM successfully captures experimental results of uniaxial tension, compact tension, and shear-tension tests within a unified framework.

Keywords: Gurson-cohesive modeling (GCM), Continuum damage, Discrete fracture, Regularization-free

References:

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[2] A.L. Gurson, Continuum theory of ductile rupture by void nucleation and growth, *J. Eng. Mater. Technol.* 99 (1977) 2–15.

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Speaker



Kyoungsoo Park

Prof. | Yonsei University

MS 096: Coupled Multi-Physics Mechanics of Geomaterials for Energy and Environmental Applications

4:00 PM – 6:00 PM | Location: UMC 415-417

Chair(s): Angelica Tuttolomondo; Anne-Catherine Dieudonné

Moderators



Anne-Catherine Dieudonné

Associate Professor Multiphysics Geomechanics | Delft University of Technology

ID 758: Modeling High-Temperature Effects in a Bentonite Buffer based on a Large-Scale Field Test

4:00 PM – 4:20 PM

Author(s): Radhavi Samarakoon, University of Massachusetts Dartmouth; Liange Zheng, Lawrence Berkeley National Laboratory

The long-term performance of bentonite buffers in deep geological repositories for high-level nuclear waste is critical for the safety of engineered barrier systems (EBS). While bentonite behavior at temperatures up to 100°C (the prescribed thermal limit for most repository designs) has been extensively studied, data on coupled thermo-hydro-mechanical (THM) processes at higher temperatures (>100°C), however, remains limited. This gap in knowledge constrains repository designs that could potentially benefit from higher thermal limits. To address this, the HotBENT project—a large-scale field experiment located at the Grimsel Test Site in Switzerland—was established to investigate bentonite evolution under temperatures reaching up to 200°C. This work presents the ongoing field test, and the development of a 3D coupled thermo-hydro-mechanical (THM) model used to interpret the experimental data.

The HotBENT experiment, constructed in the FEBEX drift, consists of four heater modules with varying target temperatures (175°C to 200°C) and bentonite types. Heating commenced in September 2021, and by May 2022, all heaters had reached their target temperatures. A comprehensive sensor network monitors key variables, including temperature, pore pressure, relative humidity (RH), and mechanical pressure. Parallel to the field test, a multi-institutional modeling platform was established to develop predictive and interpretative models. This study focuses on the development of a full 3D THM model using the TOUGH-FLAC simulator. The 3D model encompasses Heaters 1 and 2 and accounts for the granular bentonite backfill, bentonite block pedestals, and the surrounding granitic host rock.

Comparison of simulation results with field data shows that the model effectively captures the general trends of THM behavior. Temperature predictions generally align with field measurements, though discrepancies exist in the bentonite backfill. The model successfully reproduces the sharp decline in RH near heaters due to drying and the subsequent gradual recovery driven by hydration from the host rock. Gas pressure simulations mirror temperature trends, showing early peaks near heaters followed by stabilization. Porosity evolution indicates significant spatial heterogeneity, with drying-induced shrinkage near heaters and swelling near the rock interface.

Speaker



Radhavi Samarakoon

Affiliated Faculty | Lawrence Berkeley National Laboratory

ID 846: A soil–water retention model for deformable soils accounting for capillary and adsorptive mechanisms

4:20 PM – 4:40 PM

Author(s): Agostino Walter Bruno, University of Genoa; Angelica Tuttolomondo, École Polytechnique Fédérale de Lausanne (EPFL); Vincent Rozzi, ENTPE, Université de Lyon; Svetlana Babi, École Polytechnique Fédérale de Lausanne (EPFL); Antonin Fabbri, ENTPE, Université de Lyon; Domenico Gallipoli, University of Genoa; Lyesse Laloui, École Polytechnique Fédérale de Lausanne (EPFL)

Accurately predicting the water retention behaviour of unsaturated soils is critical for a wide range of geo-energy and geo-environmental applications, including the disposal of high-level nuclear waste (Dupray et al., 2013), the design of energy geo-structures and subsurface storage systems (Laloui and Di Donna, 2013) and the remediation of contaminated sites (O'Brien et al., 2018). Soil-water retention is governed by both capillary and adsorption mechanisms, yet the interplay between these two regimes remains poorly understood.

To address this limitation, the present work proposes a novel soil-water retention model expressing the degree of saturation S_r as the sum of the two adsorptive (S_r^a) and capillary (S_r^c) components. The adsorptive component S_r^a is calculated using a physically consistent formulation that uniquely relates the average thickness of the adsorbed water film to the soil suction s . The capillary component S_r^c is calculated using a modified form of the van Genuchten (1980) retention model for deformable soils, which relates the degree of saturation to both soil suction s and void ratio e . The model depends on nine parameters: five governing the adsorptive contribution, three governing the capillary contribution and one defining the maximum overall degree of saturation. Notably, most of these model parameters correspond to intrinsic soil properties or can be reasonably estimated using standard assumptions.

The model is calibrated and validated against the experimental dataset of Babi et al. (2025), who proposed an innovative thermogravimetric-based experimental methodology to quantify both capillary and adsorbed water in sodium-based MX80 bentonite samples. The results show that the model accurately captures the significant presence of adsorbed water at relative low suctions, as well as a non-negligible contribution of capillary water persisting at high suctions. Future work will focus on further investigating the capillary and adsorptive soil-water retention behaviour by accounting for hysteresis effects associated with drying and wetting paths.

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Speaker



Angelica Tuttolomondo

Dr. | EPFL-ENAC-LMS

ID 876: Investigating the Prediction of Thermally Induced State and Property Changes in a Clayey Soil

4:40 PM – 5:00 PM

Author(s): Mohd Sheob, University of Colorado Boulder; Srikanth S. C. Madabhushi, University of Colorado Boulder

Understanding the influence of temperature on the strength of saturated soils remains a complex issue in the thermomechanical modeling of soils. Experimental evidence consistently shows that thermal loading can modify shear strength; however, the extent to which these changes arise from stress-state evolution, yield surface modification, or other intrinsic variations in soil properties remains difficult to decouple, both experimentally and conceptually.

This study investigates the temperature dependency of the undrained shear strength (s_u), inferred from T-bar penetration data. The T-bar results indicate a negative temperature dependency of undrained shear strength, with s_u decreasing as temperature increases; however, it remains challenging to distinguish whether this response is governed by changes in soil state, material properties, or their combined effects. The observed experimental trends are interpreted with various thermo-mechanical extensions of the Modified Cam-Clay framework, e.g., variations of the stress state, pre-consolidation pressures and/or critical state modelling parameter. The modifications are used to examine alternative hypotheses, broadly distinguished between changes of state versus change of properties. Firstly, predictions of the undrained shear strength are made when the temperature is assumed only to induce a change in soil state, i.e., thermal pressurization, while the slope of the projection of the critical state given by M remains constant. Secondly, two changes of property are explored, temperature-dependent variations in M are introduced to represent potential fabric-level or interparticle friction effects, as well as changes of dilatancy via the pre-consolidation pressure that could manifest as altered excess pore pressure predictions. Overall, the link between experimental results versus the range of thermo-mechanically plausible modifications to constitutive models that could capture these trends are compared and contrasted, providing greater insight into both the experimental results and avenues to incorporate thermomechanical effects into simple and more advanced constitutive models. Ultimately the findings are contextualized with the impact of temperature driven changes of soil strength on the performance of geostructures under thermally affected conditions.

Speaker



Mohd Sheob

Graduate Research Assistant | University of Colorado Boulder

ID 911: A coupled hydro-mechanical model for gas pathway initiation and propagation in saturated bentonite

5:00 PM – 5:20 PM

Author(s): Zhaojiang Huang, Delft University of Technology; Joaquín Liaudat, Technical University of Darmstadt; Philip Vardon, Delft University of Technology; Michael Hicks, Delft University of Technology; Anne-Catherine Dieudonné, Delft University of Technology

Geological disposal is widely recognized as a long-term solution for isolating high-level radioactive waste. Compacted bentonite is a key buffer material due to its low hydraulic conductivity, important swelling capacity, and high retention capacity. After repository closure, gas generation is expected. Gas pressurization can lead to the development of preferential gas pathways, potentially affecting the buffer performance. A thorough understanding of the hydro-mechanical mechanisms governing gas migration and breakthrough in bentonite is therefore essential for ensuring the long-term safety and performance of geological disposal systems.

Previous laboratory and field studies [1-2] have demonstrated that gas migration in compacted bentonite is accompanied by the development of preferential pathways and localized structural changes. However, the strongly coupled hydro-mechanical nature of pathway initiation and propagation remains incompletely understood. In this study, a fully coupled pneumo-hydro-mechanical (PHM) finite element model is adopted to simulate a gas injection experiment on saturated bentonite. Continuum elements are used to represent the continuum porous medium, while interface elements [3] are introduced to represent potential gas pathways. The experimental injection conditions are carefully reproduced to allow direct comparison with laboratory observations.

The results indicate that the model captures the main features observed in experiments and provides insights into the mechanisms governing gas migration. The simulations show that the sudden increase in local pore pressure is associated with gas entry into the bentonite, and that gas pathways propagate rapidly after initiation, leading to gas breakthrough when the pathway reaches the top of the sample. Gas migration remains localized within the pathway, while the surrounding porous medium maintains a high degree of saturation, consistent with previous experimental observations [4]. Sensitivity analyses further indicate that the mechanical properties, such as Young's modulus and Poisson's ratio, strongly influence the stress conditions and hydro-mechanical coupling effects controlling gas pathway propagation.

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Speaker



Zhaojiang Huang

Mr. | Delft University of Technology

ID 454: Damage-based modeling and poromechanics – influence of anisotropy of the Biot coefficient on hydraulic fracturing

5:20 PM – 5:40 PM

Author(s): Saif-Eddine Chadoi, Universite de Pau et des Pays de l'Adour; Gilles Pijaudier-Cabot, Universite de Pau et des Pays de l'Adour; Christian La Borderie, Universite de Pau et des Pays de l'Adour

In many applications such as hydrocarbon production or in situ leaching (ISL) for ore production in mining engineering, efficiency strongly depends on the permeability of the geological formation. Permeability must be sufficiently high to ensure effective fluid circulation. In low-permeability formations, geomechanical stimulation techniques, such as hydraulic fracturing, electrohydraulic fracturing, or dynamic fracturing, are required to enhance this process.

The stimulated reservoir is a porous medium composed of a solid skeleton and a pore fluid, whose interactions govern both mechanical deformation and fluid flow. From the mechanical point of view, damage and cracking can be captured by a continuum damage model. Here, an isotropic damage model is implemented. Permeability is directly linked to fracture opening induced by damage. Because damage is isotropic, permeability is often isotropic too. In the present approach, the fracture aperture is computed from the damage model and the permeability is a function of this fracture aperture following a classical cubic law. It is the largest eigenvalue of the permeability tensor, corresponding to the most permeable direction according to the assumption of isotropy. Poromechanical effects play a key role, and more specifically the Biot coefficient which governs the coupling between pore pressure and effective stress. An original modeling strategy is proposed by introducing an anisotropic Biot coefficient. The Biot coefficient is assumed to be larger along the most permeable direction and smaller in the perpendicular direction.

Results focus on a comparative analysis between isotropic and anisotropic Biot coefficient formulations with an emphasis on hydraulic fracturing. The influence of the anisotropy of the Biot coefficient is examined on the crack path and crack length upon hydraulic fracturing. Compared to the anisotropic case, the state of effective stress near the crack tip exhibits less compression due to the pore pressure perpendicular to the crack direction in the isotropic case. Anisotropy is found to moderate mesh sensitivity on crack paths in computations and it induces also larger crack lengths.

Speaker



Saif Eddine Chadoi

PhD student | Universite de Pau et des Pays de l'Adour

ID 544: Coupled Thermo-Hydro-Mechanical Performance of Energy Micropiles in Sands

5:40 PM – 6:00 PM

Author(s): Kaveh Roushan, University of Missouri; Askar Janalizadeh Choobbasti, Babol Noshirvani University of Technology, Iran; Hessem Yazdani, University of Missouri

Energy micropiles (EMPs) are foundation elements that combine structural underpinning with geothermal heat exchange to enable simultaneous structural and energy retrofitting in space-constrained urban environments. Owing to their high slenderness ratio and negligible end-bearing capacity, EMPs mobilize load-transfer mechanisms that can produce coupled thermo-hydro-mechanical (THM) behavior distinct from that of conventional energy piles. This study employs 3D finite element simulations, validated against experimental data from large-scale physical modeling tests, to investigate the THM response of EMPs in sand subjected to cyclic thermal loading under dry and fully saturated states. The influences of critical design variables, including inlet fluid temperatures (47°C, 49°C, and 51°C) and thermal loading durations (6, 12, and 24 hours), on structural stability and heat-exchange efficiency are evaluated. Results show that saturation considerably increases heat injection rates while fundamentally altering thermally-induced restraint at the soil–structure interface relative to dry conditions. Saturated conditions are also observed to result in distinct axial stress distributions featuring a downward shift in the thermal null point. In addition, cyclic thermal loading drives progressive stress redistribution and the accumulation of irreversible head settlements (ratcheting) along the EMP shaft, highlighting potential serviceability constraints under repeated thermal cycles.

Speaker



Kaveh Roushan

Postdoctoral Researcher | University of Missouri

MS 082: Innovations and Advances in Passive, Active, and Semi- active Structural Control

4:00 PM – 6:00 PM | Location: UMC 382-384-386

Chair(s): Nicholas Wierschem; P. Scott Harvey

Moderatorss



Nicholas Wierschem

Associate Professor | University of Tennessee



P. Scott Harvey

Associate Professor | University of Oklahoma

ID 97: Periodic Metamaterials with Multi-Resonators for Passive Vibration Control in Civil Structures

4:00 PM – 4:20 PM

Author(s): Mohsen Amjadian, The University of Texas Rio Grande Valley; Quoc-Bao Ta, The University of Texas Rio Grande Valley

In recent years, advanced vibration isolators have attracted significant attention for mitigating the effects of extreme dynamic loads, such as earthquakes, on multi-story buildings. The conventional methods largely center on enhancing energy dissipation, refining isolator flexibility, and shifting the natural frequencies of the building away from the dominant frequency of the earthquake. In this context, periodic metamaterials have emerged as a promising solution, employing engineered lattice structures with embedded resonators that generate frequency bandgaps to filter targeted frequencies that can be destructive. By incorporating multiple resonators tuned to several dominant frequencies, periodic metamaterials broaden their vibration suppression range and improve damping performance, paralleling the efficiency of multiple tuned mass dampers within a more compact and integrated framework. This paper presents the development of a multi-resonator periodic metamaterial for improved vibration control in civil structures. Initially, a series of lattice architectures with varying configurations is analyzed using finite element modeling in COMSOL to optimize their vibration mitigation efficiency across a broad frequency range. Based on these results, an optimized configuration is identified and subjected to experimental validation. The experimental setup employs two accelerometers, one mounted at the base and another at the free end of the optimized lattice, to measure the ratio of output acceleration to input acceleration in the frequency domain, known as the transmissibility ratio. By combining numerical simulations with experimental measurements, this study demonstrates the potential of multi-resonator periodic metamaterials as next-generation vibration mitigation solutions, paving the way for more resilient and adaptive infrastructural systems.

Speaker



Quoc-Bao Ta

Postdoctoral Fellow | The University of Texas Rio Grande Valley

ID 195: Nonlinear Dynamic Modeling of 3D-Printed Chiral Metamaterial Beams

4:20 PM – 4:40 PM

Author(s): Pushp Raj Poudel, Iowa State University; Han Liu, Iowa State University; Simon Laflamme, Iowa State University

Advances in additive manufacturing have enabled the fabrication of metamaterials to become possible and cost-effective, sparking significant research interest. While these materials are widely applied at micro- and nanoscales, their large-scale deployment in vibration mitigation and energy dissipation remains limited. This is largely due to the challenges associated with their design and fabrication. Of interest to this research is their poorly understood nonlinear dynamics that impede their engineering for field applications. In prior research, we have demonstrated that a semi-active chiral metamaterial beam can be utilized to provide both stiffness and supplemental damping. Here, we build on these results and construct a simple dynamic model that characterizes the beam's behavior, with the objective of simplifying the design and analysis tasks. To do so, we fabricated beam specimens 3D-printed from poly lactic acid and subjected the beams to quasi-static and static loads under a three-point bending setup. A numerical model is constructed in ANSYS to produce synthetic data. A methodology is established to construct a simplified dynamic model that accounts for viscoelasticity, friction, and displacement-dependent behaviors. The key novelty of this methodology lies in the separation and modeling of frictional and viscoelastic mechanisms, which enables the generation of response hysteresis, peak response amplitudes, and energy loss across different loading frequencies. Overall, the proposed methodology successfully enables the modeling of the chiral metamaterial beam, capturing most of its nonlinear dynamic response. The findings can serve as a pathway for designing large-scale structures with enhanced dissipation behavior while maintaining adequate strength.

Speaker



Pushp Raj Poudel

Graduate Research Assistant | Iowa State University

ID 566: Tuned Inerter-based Devices in Isolation Systems: Optimization and Robustness Analysis

4:40 PM – 5:00 PM

Author(s): Deidra Anderson, University of Tennessee; Nicholas Wierschem, University of Tennessee

Tuned viscous mass dampers (TVMD) and tuned inerter dampers (TID) consist of configurations of springs, dampers, and inerters and have been recently investigated for vibration control in base isolation systems. The primary way these devices improve the performance of isolation systems is by reducing the impact of large displacements and forces associated with the isolation mode of isolated systems. These devices, however, are often only as effective as their ability to maintain their tuning as changes in structural properties can lead to a loss of performance. Therefore, robustness studies have considered variations to the isolation stiffness layer, system inertance-to-mass ratio, and device's stiffness and damping. An uninvestigated topic, however, is the consideration of various optimization metrics on device design and the effects in performance when the system's primary mass is subjected to fluctuations. In this numerical study, isolation performance and optimized system parameters in the TID and TVMD are compared considering optimization with several different objective functions and constraints on the device stiffness and damping parameter values. Furthermore, optimization of the TVMD and TID is considered across a range of inertance values. Subsequently, robustness of the TID and TVMD systems are assessed with detuning by adjusting the system's mass. The results of this work show that the TVMD optimization often yields a high-stiffness and high-damping device that is not in-fact tuned to the isolation mode of the structure and, if a multi-metric optimization strategy is utilized, the TVMD can yield better performance than the TID in most of the performance metrics considered. The parameters of these optimized TVMD, particularly the high damping, may not be feasible and constraints on the TVMD damping and stiffness parameters yields a TVMD that does tune to the isolation mode of the structure. The performance of this isolation mode-tuned TVMD is generally inferior to the TVMD optimized without parameter constraints, but still generally outperforms the TID. In contrast to the TVMD, the TID optimization consistently yields a tuned device with similar parameters and performance. This study also showed that the non-tuned TVMD has higher robustness to changes in system mass compared to the tuned TVMD and TID. Overall, this study shows that the TVMD is generally preferable to the TID considering its better performance and potentially lower sensitivity to detuning; however, the optimization of the TVMD is less straightforward than the optimization of the TID and requires an understanding of the implication of specific objective functions and of the feasibility of the parameters yielded from the optimization.

Speaker



Nicholas Wierschem

Associate Professor | University of Tennessee

ID 707: Modeling, Characterization, and Testing of a Vertical Isolation System with Quasi-zero Stiffness for Building Content Protection

5:00 PM – 5:20 PM

Author(s): Bethany Hutto, University of Oklahoma; Philip Harvey, University of Oklahoma

This paper explores the design of a vertical isolation system utilizing the nonlinear behavior of laterally loaded, buckled beams to generate negative stiffness. This negative stiffness is then counteracted by a positive, linear stiffness from parallel springs to create quasi-zero stiffness (QZS). The QZS allows for a mass supported by the system to be effectively isolated from the effects of vertical dynamic motion at the base of the system, while also exhibiting greatly reduced static deformations. An experimental model was produced for the system, with a focus on using lightweight materials and allowing for a low, compact profile. Carbon fiber beams clamped between rigid end blocks were used to realize the negative stiffness element; conventional helical (compression) springs provided positive stiffness. Four beam-spring units were assembled to construct an isolation layer capable of supporting a sensitive piece of equipment (e.g., a server cabinet). Static testing was performed on the individual beam-spring units, with parametric variation provided by the beam geometry, the imposed end shortening on the beam, and the spring stiffness. Then, real-time hybrid simulation (RTHS) tests were performed to evaluate the systems isolation performance under earthquake-induced floor motions.

Speaker



P. Scott Harvey

Associate Professor | University of Oklahoma

ID 970: Ideal Controllable Damper Model Simulation and Challenges

5:20 PM – 5:40 PM

Author(s): Erik Johnson, University of Southern California

Controllable semiactive dampers, such as variable orifice or magnetorheological fluid dampers, have been simply modeled as exactly exerting a commanded desired force when that force is dissipative, and no force (or some minimal nominal damping level) when the desired force is not dissipative. This study evaluates the behavior of such a model with multiple approaches to a system simulation: first with an exact simulation that perfectly captures the on-off behavior of the ideal damper model, and subsequently with fixed-time-step solvers. The latter are sometimes observed to exhibit oscillations across the on-off boundary; smaller time steps do affect the amplitude of these oscillations but do not eliminate them, potentially leading to an inaccurate assessment of control performance.

Speaker



Erik Johnson

Professor & Vice Dean | University of Southern California

ID 317: Optimized Intensifying Artificial Accelerations for Efficient Fragility and Risk Assessment under Uncertainty

5:40 PM – 6:00 PM

Author(s): Mohammad Amin Hariri-Ardebili, NIST; Siamak Sattar, NIST; Sissy Nikolaou, NIST

Performance-Based Earthquake Engineering (PBEE) workflows rely on probabilistic nonlinear response analysis to connect seismic intensity measures (IMs) to engineering demand parameters (EDPs) and, ultimately, to damage and loss metrics. In practice, Incremental Dynamic Analysis (IDA) and related cloud methods remain computationally demanding because they require many nonlinear simulations across multiple scaled records and hazard levels. Intensifying Artificial Accelerations (IAAs) provide a computationally efficient alternative by driving a structural model from elastic response through progressive nonlinearity and up to collapse within a single, continuously intensifying excitation. In this study, IAAs are treated as optimized excitations: starting from a random (white-noise) seed, the acceleration time series is shaped through computationally intensive non-constrained optimization so that selected dynamic attributes track prescribed targets (e.g., spectral ordinates, nonlinear displacement response, duration proxies, and energy/damage measures) via a weighted, hierarchical objective formulation.

Because optimization-based excitation design introduces its own randomness and because PBEE results are sensitive to ground-motion sampling, this paper focuses on quantifying bias and uncertainty in IAA-based fragility estimates relative to IDA. The proposed framework explicitly distinguishes and propagates multiple variability sources---record-to-record, set-to-set, and group-to-group variability---to prevent conflation of dispersion mechanisms and to identify where IAAs can (or cannot) replace ensembles of real records. Using 32 publicly available IAAs spanning five generations (reduced to 10 representative generations by within-series averaging) and nine generic real/stochastic ground-motion sets for IDA, we evaluate (i) similarity of entire response curves, (ii) collapse-capacity agreement, and (iii) resulting fragility parameters.

To enable probabilistic use without generating new IAAs, the method incorporates a conditional time--IM conversion that leverages external response spectra and provides consistent 16/50/84% IM ordinates, and introduces a spectrum-compatible dispersion estimator based on the log-space spread of the 16% and 84% fractiles. Collectively, the results delineate when optimized IAAs can accurately reproduce IDA medians and dispersions, and when additional calibration or hybrid strategies are required for robust risk assessment of nonlinear structural systems.

Speaker



Amin Hariri

Researcher | NIST

MS 098: Meshfree, Peridynamic, and Particle Methods: Advancements and Applications

4:00 PM – 6:00 PM | Location: HUMN 1B80

Chair(s): Sheng-Wei Chi; Jiun-Shyan (JS) Chen; Mike Hillman; Pablo Seleson; Tsung-Hui (Alex) Huang; Kuan-Chung Lin

Moderators



Sheng-Wei Chi

Associate Professor | University of Illinois Chicago

ID 227: A Damaged-Kernel Enhanced General-Purpose Lagrangian Reproducing Kernel Kirchhoff--Love Shell Formulation

4:00 PM – 4:20 PM

Author(s): Jiarui Wang, Southern University of Science and Technology; Ke Ma, Vanderbilt University; Yuri Bazilevs, Vanderbilt University

In the Lagrangian reproducing kernel particle method (RKPM) [1], the basis functions are constructed with reference to the material configuration, and this formulation offers well-known advantages over traditional Lagrangian mesh-based approaches in large-deformation problems. While the approximation-function values are stored and merely accessed during the simulation, which provides efficiency, the necessary assumption of one-to-one mapping fails when the deformation becomes extreme. Moreover, the topology of material points remains unchanged when the separation happens in the case of fracture and fragmentation simulations.

In this work, a damaged-kernel enhanced general-purpose RKPM thin shell formulation is introduced. The degenerated shell approach is employed in the present formulation, where the structure is considered as a 3D solid that is subjected to the constraints of the Kirchhoff--Love shell kinematics [2]. A Lagrangian formulation is used. Principal component analysis (PCA) is adopted as a local parameterization technique to address the challenge of surface geometry representation of meshfree methods, and the isoparametric RK approximation is employed for the approximation of the kinematic variables. An in-plane Taylor-series-expansion-based enrichment [2] is developed to stabilize nodal quadrature. The damage-based kernel degeneration algorithm is proposed to effectively simulate material separation. The effectiveness of the proposed RKPM KL shell formulation is demonstrated using an extensive set of linear-elastic and finite-deformation inelastic test cases.

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Speaker



Yuri Bazilevs

Prof. | Vanderbilt University

ID 203: Continuum-Based Particle Gas (CPG): A Meshfree Method for Airbag Deployment Simulation

4:20 PM – 4:40 PM

Author(s): Edouard Yreux, Ansys, part of Synopsys

Over the past decades, airbags have evolved from simple passive restraints to complex systems distributed throughout vehicles to enhance occupant safety. This advancement has complicated numerical modeling, especially due to the Fluid-Structure-Interaction during inflation. Early models used a uniform pressure approach, which poorly captured deployment dynamics. The later-introduced Corpuscular Particle Method (CPM), based on kinetic gas theory, improved accuracy for complex designs but now faces limitations in resolving local flow during early deployment.

The growing complexity of airbag systems and the limitations of existing modeling techniques led to mounting pressure from the automotive industry for a more accurate and reliable simulation approach. To this end, a novel particle method known as Continuum-based Particle Gas (CPG) has been introduced. CPG retains the flexibility provided by particle methods by eliminating the need for meshing the fluid volume (critical for highly transient FSI) while providing precise gas dynamics and accurate fluid structure interaction.

In this presentation, we introduce a novel method for simulating airbag deployment known as Continuum-based Particle Gas (CPG), which relies on continuum physics principles. Like CPM, CPG is a particle-based approach that eliminates the need for meshing the airbag's internal volume. However, CPG is formulated directly in the strong form of the governing equations and solves the compressible Navier--Stokes equations coupled with an ideal-gas equation of state. Our emphasis will be on explaining the theoretical foundations of the CPG solver and showcasing numerical examples, supported by theoretical analysis or experimental validation studies.

Speaker



Edouard Yreux

R&D Engineering, Architect | Synopsys

ID 263: Dynamic Quasi-Brittle Fracture: A Blended Approach

4:40 PM – 5:00 PM

Author(s): Debdeep Bhattacharya, Grinnell College; Semsi Coskun, NuroI Teknoloj,; Davood Damircheli, Louisiana State University; Robert Lipton, Louisiana State University

Quasi-brittle materials are characterized by progressive damage and crack propagation, leading to softening and irreversible strain after the peak load is reached. Examples include concrete as well as many types of rocks, shale and sandstone. The approach taken here is formulated using a nonlocal constitutive law together with a phase field that is nonlocal in space and time. The displacement field inside the material is shown to be uniquely determined by an initial boundary value problem. The fracture set is characterized by the evolving phase field taking the value one inside intact material and zero in the fully damaged material. The theory satisfies energy balance, with positive energy dissipation rate in accordance with the laws of thermodynamics. Notably, these properties are not imposed but follow directly from the evolution equation by multiplying the equation of motion by the velocity and integrating by parts. The field theory uses a peridynamic interpretation of Newton's 2nd law to evolve the displacement inside the material and there is no separate equation for phase field evolution. Instead, the phase field is part of a history dependent constitutive law dynamically coupled to the displacement field. Elasticity, fracture energy, and strength are independent of each other in this model. Here, a characteristic length scale L is derived using geometric measure theory and is proportional to the ratio of fracture toughness to material strength. The formulation delivers a mesh-free method for predicting crack patterns. The computational method successfully captures the cyclic load–deflection response of crack mouth opening displacement, the structural size-effect related to ultimate load, and fracture nucleating from boundary defects. It provides dynamic results identical to dynamic phase field methods introduced in [1]. These results are reported in [2], [3].

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Speaker



Robert Lipton

Professor | Louisiana State University

ID 281: A Comparison of F-Bar and Mixed Formulations for Mitigating Volumetric Locking in an Implicit RKPM

5:00 PM – 5:20 PM

Author(s): Thomas Mader, BOKU University; Peter Gamnitzer, University of Innsbruck; Heiko Gimperlein, University of Innsbruck; Matthias Neuner, BOKU University

Numerical simulations of elastoplastic materials often suffer from volumetric locking, particularly when plastic flow induces incompressible or nearly-incompressible constraints. In meshfree methods like the Reproducing Kernel Particle Method (RKPM), these constraints can lead to spurious pressure oscillations and an artificial stiffening of the system response. This work presents a comparative study of two strategies to mitigate volumetric locking within an implicit semi-Lagrangian RKPM framework.

The first strategy utilizes an F-Bar deformation gradient projection. To facilitate the necessary volumetric-deviatoric split in a meshfree context, the method is coupled with Sub-Domain Integration (SDI), where additional quadrature points are applied by subdividing the smoothing domains used for stabilized nodal integration (SNI). This allows for the definition of smoothing domains, where the volumetric part of the deformation gradient is evaluated at nodal position to relax the volumetric constraint. The second strategy is a mixed formulation, in which the volumetric strain is treated as an independent degree of freedom. The latter is stabilized by a Variational Multiscale (VMS) approach, providing the necessary numerical stabilization to circumvent the Inf-Sup condition.

Both formulations are developed for an implicit solution procedure, with algorithmic tangent operators derived to ensure quadratic convergence. The performance of these methods is evaluated through benchmark problems in Drucker-Prager plasticity, focusing on their ability to predict limit loads and capture localized failure without volumetric locking. By comparing the results with finite element simulations, this study highlights the capabilities of the investigated methods for overcoming volumetric locking regarding accuracy, stability, and computational efficiency in implicit RKPM frameworks.

Speaker



Thomas Mader

Mr | BOKU University

ID 369: Crushing, Comminution and Fracture: Extreme Particle Deformation in Three-Dimensional Granular Aggregates

5:20 PM – 5:40 PM

Author(s): Debdeep Bhattacharya, Grinnell College; Davood Damircheli, Louisiana State University; Robert Lipton, Louisiana State University

We present a high-fidelity three dimensional computational framework for simulating the bulk mechanical behavior of granular aggregates composed of deformable brittle grains. Departing from classical discrete element methods (DEM), our approach captures both inter-particle and intra-particle deformation using a nonlocal continuum formulation based on peridynamics. Each grain is individually meshed from level-set representations, enabling accurate modeling of elastic response and autonomous fracture evolution without requiring explicit crack tracking or fragment reconstruction. We validate the method through benchmark simulations, including the Kalthoff-Winkler fracture test, crushing of hollow spheres, and compound impact-crushing scenarios. The framework is further applied to large aggregates of up to 1000 sand grains of irregular shapes reconstructed from three dimensional X-ray computed tomography. Simulations reveal convergence of bulk stress response under compression, suggesting the feasibility of constructing representative volume elements (RVEs) for multiscale modeling. Finally, we investigate the role of grain geometry and topology on the macroscopic strength of the aggregate, providing insight into microstructure-driven failure mechanisms. The framework exhibits excellent strong and weak scaling behavior, with simulations executed on up to 1600 cores, demonstrating its suitability for high-performance computing environments and large-scale modeling.

Speaker



Debdeep Bhattacharya

Dr. | Grinnell College

ID 715: A Neural-Network Enriched Reproducing Kernel Particle Method for Phase Transformation Localization Problems

5:40 PM – 6:00 PM

Author(s): Xuejun Li, University of Illinois Chicago; Sheng-Wei Chi, University of Illinois Chicago

Reproducing Kernel Particle Method (RKPM) has demonstrated its proficiency in solving problems with extreme strain rates and deformations [1]. However, introducing discontinuities in the approximation that capture heterogeneity, fracture, or strain localization remains challenging and computationally costly. Meanwhile, applying Machine Learning (ML) to computational mechanics has gained much attention. Nevertheless, obtaining solutions to mechanics problems solely through Neural Network (NN) without the aid of the existing numerical method may cause low efficiency and convergence issues. Therefore, a block-level NN has been integrated into the RK approximation to enhance the resolution of local discontinuity [2]. The Partition of Unity basis function, such as the RK shape function associated with the spatial discretization, can be combined with the continuous NN representations to improve the accuracy and the training efficiency [3]. Optimized relocation of the nodal points can also be achieved to produce the best localized behavior within the minimum computational cost. This work proposes an NN-based algorithm for the enhanced simulation of phase-transformation localization problems. This method utilizes a specifically designed NN architecture to enrich the numerical approximation of the RKPM. Novel boundary treatments and tailored numerical integration schemes are also introduced to enhance training efficiency and solution accuracy near domain boundaries. Leveraging the flexibility of the NN framework, additional advanced features, such as adaptive nodal refinement, are enabled to enhance the local behavior of discontinuity. Benchmarks, including Poisson's Equation and elasticity problems with strain localization, are utilized to evaluate the proposed method's effectiveness in terms of accuracy, stability, and convergence. The performance of the proposed method is compared with other existing approaches.

Reference:

[1] Atif, M. M. & Chi, S.-W. (2023) Concurrent semi-Lagrangian reproducing kernel formulation and stability analysis. Computational mechanics, 73(4), 873-906.

[2] Baek, J., & Chen, J. S. (2024). A neural network-based enrichment of reproducing kernel approximation for modeling brittle fracture. Computer Methods in Applied Mechanics and Engineering, 419, 116590.

[3] Du, H., & He, Q. (2024) Neural-Integrated Meshfree (NIM) Method: A differentiable programming-based hybrid solver for computational mechanics. Computer Methods in Applied Mechanics and Engineering, 427, Article 117024.

Speaker



Xuejun Li

Mr | University of Illinois Chicago

MS 095: Characterization and modeling of physical and chemical processes in porous materials across scales

4:00 PM – 6:00 PM | Location: VAC 1B20

Chair(s): Mostafa Mobasher; Pania Newell; Sara Abedi; Manolis Vevakis; Jean-Michel Pereira; Giuseppe Buscarnera; Yanni Chen; Ghassan Shahin; Rigoberto Moncada

Moderatorss



Rigoberto Moncada Lopez

LLNL



Pania Newell

Associate Professor | The University of Utah

ID 920: Chemo-mechanical equilibrium between dissolution and precipitation in porous media

4:00 PM – 4:20 PM

Author(s): Yifan Yang, Northwestern University; Giuseppe Buscarnera, Northwestern University

Dissolution and precipitation in porous media may either damage building materials or be harnessed to support sustainable subsurface engineering applications. To rationalize these effects, here the classical concept of crystallization pressure is revisited through the lens of thermodynamics. Specifically, a unified theoretical framework is developed by incorporating principles of physical chemistry, generalized poroelasticity, and the variational principle, through which the stiffness of the crystals and surrounding matrix, as well as the microstructure of the porous system, are accounted for. The framework explicitly includes inelastic "eigenstrain" terms commonly associated with precipitation and dissolution, yet assigns them to separate phases. The results yield a generalized crystallization pressure that deviates from the standard prediction, along with an estimate of anisotropic eigenstrain beyond the scope of the classical theory. Parametric analyses show that crystals with lower bulk moduli produce higher crystallization pressures, while more compliant porous skeletons accommodate greater volumetric growth. Moreover, the Poisson's ratio of crystals plays a decisive role in determining the growth direction in porous media with anisotropic microstructures. In particular, the proposed model suggests that crystals with relatively low Poisson's ratio tend to grow along and dissolve against the direction of the largest macroscopic Young's modulus of the porous skeleton, whereas those with high Poisson's ratio exhibit the opposite trend. These findings not only explain the causes of the common overestimation of the crystallization pressure embedded into the classical methods but also clarify the conditions that govern the initiation, continuation, and cessation of crystal growth and redissolution.

Speaker



Yifan Yang

Ph.D. Student | Northwestern University

ID 191: Thermo-poromechanical modeling of evaporation and pressure build up in soft nanoporous solids

4:20 PM – 4:40 PM

Author(s): Mohammadali Behboodi, University of Colorado Boulder; Yida Zhang, University of Colorado Boulder

The thermomechanical response of soft nanoporous materials under heating is inherently a coupled process, in which heat and fluid phases diffuse through the pore network and induce significant deformations in the solid matrix. In the case of nanoporous polymers (cellulose, hydrogels), the pore fluid may exist either as a vapor or as a denser, less mobile phase that interacts with the polymer chains. The latter, representing the portion of fluid that is not in the vapor state, is referred to as the excess phase. The present framework builds upon the poromechanics formulation of Coussy [2004] and its subsequent generalization to explicitly account for the surface phase Zhang [2018]. We begin by stating the balance laws for the solid, vapor, and excess phases, and then combine them to formulate the Clausius–Duhem inequality for the system. All phases are assumed to be homogenized within the representative elementary volume (REV) according to their respective volume fractions. In contrast to previous studies of adsorption-induced deformation in solid nanoporous media [Behboodi and Zhang, 2025], polymers do not permit a well-defined solid surface, and the notion of surface tension becomes ill-posed. Because adsorption in polymers reflects the attraction of fluid molecules to polymer chains throughout the bulk, it is treated as a volumetric rather than surface phenomenon. Treating sorption as a bulk process naturally introduces an additional pressure contribution, commonly referred to as the disjoining pressure, serving as the thermodynamic force conjugate to the excess-phase volume, rather than to the film thickness as described in classical surface science treatments. Such disjoining pressure is the dominant driver of volumetric changes in nanoporous materials during sorption. When a pre-moistened sample is heated, the supplied thermal energy can exceed the sorption energy, leading to drying and the expected macroscopic shrinkage of the solid framework. However, the very low permeability of such materials prevents the newly generated vapor from escaping at the same rate it is produced. This may result in local moisture accumulation and transient vapor pressure buildup, which in turn induces pronounced local bulging as opposed to shrinkage. The objective of this study is to develop a unified framework that consistently couples these mechanisms and captures their combined influence on material behavior.

Speaker



Mohammadali Behboodi

Graduate Research Assistant | University of Colorado Boulder

ID 777: Changes in hydromechanical behavior of olivine-rich rocks during serpentinization

4:40 PM – 5:00 PM

Author(s): Ummu-kulthum Lawal, Texas A&M University; Kiseok Kim, Texas A&M University

Serpentinization induces hydrogen generation and systematically modifies the mechanical, microstructural, and transport properties of ultramafic rocks, with implications for deformation, fluid migration, and seismic signatures in subduction environments. Despite its significance, the coupled evolution of mineral reactions, fracture development, and poromechanical response remains incompletely understood.

We experimentally simulated serpentinization in dunite under elevated temperature and pressure conditions, with parallel dry heat-treated specimens used for reference. Mechanical testing, gas permeability measurements, and multiscale microstructural characterization were performed to capture the integrated response of the rock during reaction progress. The experiments reveal a pronounced reduction in poromechanical properties accompanied by evolving fracture networks and changes in pore structure. Mineralogical analyses confirm progressive reaction of primary phases and associated solid-volume changes, while imaging and porosity measurements indicate concurrent microfracture generation and partial fracture occlusion by secondary minerals.

Gas permeability measurements exhibit an evolution that reflects the competition between reaction-induced damage and mineral volume expansion. Together, these observations demonstrate a tightly coupled chemo-hydr-mechanical pathway in which serpentinization simultaneously alters the rock framework and reorganizes its fracture-controlled transport properties.

Speaker



Kiseok Kim

Assistant Professor | Texas A&M University

ID 236: PINN-Based Modeling of Evaporation-Driven Salt Transport and Thermal Conductivity Evolution in Unsaturated Soils

5:00 PM – 5:20 PM

Author(s): Yuan Feng, University of Maryland; Jongwan Eun, University of Maryland; Semih Ciftci, University of Maryland

Salt transport in unsaturated soils governs salinization, evaporation dynamics, and the evolution of thermal and hydraulic properties in natural and engineered geoenvironmental systems. This study investigates the coupled processes of saltwater migration, evaporation-induced salt accumulation, and the resulting changes in soil thermal conductivity under controlled drying conditions. Laboratory experiments were conducted using saline pore fluids to monitor moisture redistribution, salt precipitation, and temperature-dependent thermal conductivity during evaporation. Results show that evaporation induces upward saltwater transport and localized salt accumulation near the evaporation front, producing pore-scale alterations and a nonlinear reduction in thermal conductivity. Both the magnitude and spatial distribution of salt accumulation are strongly influenced by evaporation rate and initial salinity. To represent the coupled thermal–hydraulic–chemical processes, a physics-informed neural networks (PINNs) framework was developed to solve the governing equations for unsaturated flow, vapor diffusion, heat transfer, and salt advection–diffusion. Experimental observations were incorporated as soft constraints to obtain continuous spatiotemporal predictions of moisture content, salinity, and thermal conductivity. The model reproduces measured trends without numerical stabilization or mesh refinement. The combined experimental and modeling results demonstrate the potential of PINNs for simulating evaporation-driven salinity effects and associated property evolution in unsaturated soils.

Speaker



Jongwan Eun

Associate Professor | University of Maryland

ID 426: Computational Modeling Of Blood Clots As Soft Heterogeneous Structures Immersed In Flow

5:20 PM – 5:40 PM

Author(s): Debanjan Mukherjee, University of Colorado Boulder; Chayut Teeraratkul, University of Colorado Boulder; Maurizio Tomaiuolo, Children's Hospital of Philadelphia; Timothy Stalker, Thomas Jefferson University

Blood clots play a central role in ensuring physiological wound healing and hemostatic response. Pathologically formed clots, on the other hand, are key players in major diseases like heart attack and stroke. These diseases continue to account for the leading causes of death and disability worldwide. Understanding the behavior of realistic blood clots in human vascular flow environments is therefore highly significant. In vivo experimental models of clotting pose many challenges, and are not often amenable to provide predictions at a human subject-specific level. Consequently, computational modeling has enabled novel avenues to address these hurdles. Yet, high fidelity computational models of blood clotting and clot-related phenomena face the challenges of resolving the growth, deformation, and fragmentation of an arbitrarily shaped heterogeneous blood clot in physiological pulsatile flow. Here, we will illustrate the development of customized numerical methods fundamentally based on residual-based stabilized finite element algorithms, that we have developed for resolving realistic clot-flow interactions and clot behavior. By leveraging immersed domain approaches with meshes that are not required to conform to the clot boundary, we gain valuable computational efficiency for modeling realistic timescales of clotting phenomena. We will discuss computational approaches to incorporate dynamic clotting data directly from in vivo experimental models. By pairing our numerical algorithm with automated analysis of dynamic intravital imaging data, we have devised a novel framework named IVISim, that can provide rich quantitative insights on clot growth and deformation under pulsatile flow. Typically, clots are deformable heterogeneous aggregates of platelets, fibrin strands, and red blood cells. We will also illustrate techniques to explicitly model this heterogeneity in clot composition and micro-architecture, towards developing the first micro-mechanics driven model of human whole blood clots. We will demonstrate how this resulting model can enable computational replication of phenomena like clot contraction, which are intractable to model using other conventional approaches. We will close by sharing some of our ongoing efforts towards releasing a compilation of these tools and algorithms as open-source software for the broader scientific community.

Speaker



Debanjan Mukherjee

Assistant Professor | University of Colorado Boulder

ID 990: Uncertainty quantification in machine learning–based homogenization of porous materials

5:40 PM – 6:00 PM

Author(s): Minh-Chien Trinh, University of Utah; Pania Newell, University of Utah

Machine learning (ML) has emerged as a powerful tool for accelerating multiscale modeling of porous materials by enabling fast surrogate predictions of effective mechanical properties from microstructural descriptors. However, the reliability and generalizability of ML-based homogenization are strongly influenced by uncertainties arising from microstructural variability, representative volume element (RVE) size, and numerical discretization. The combined impact of these factors on prediction error and uncertainty propagation in ML surrogates remains insufficiently characterized.

This work investigates uncertainty quantification and error propagation in ML-based homogenization frameworks for porous materials, with an emphasis on the effects of RVE size and finite element discretization. A dataset of synthetic porous microstructures is generated, with meshes created using Gmsh and RVE analyses performed in FEniCS. Numerical homogenization is employed to extract effective mechanical properties of heterogeneous porous structures. Using this framework, we systematically examine how porosity and pore morphology influence uncertainty in the computed properties. High-fidelity numerical homogenization is applied across varied RVE dimensions and mesh resolutions, and supervised ML models are trained to predict effective responses from microstructural descriptors. The models are evaluated across multiple length scales and discretization settings.

Results demonstrate that both RVE selection and discretization consistency play critical roles in ML-based homogenization accuracy and uncertainty bounds. The study provides quantitative guidance for constructing training datasets and uncertainty-aware ML surrogates for multiscale modeling of porous materials.

Keywords: Porous materials, Representative volume element (RVE), Finite element discretization.

Speaker



Minh Chien Trinh

Postdoctoral Research Associate | University of Utah, United States

MS 077: Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications (Sponsored by ASCE Aerospace Division)

4:00 PM – 6:00 PM | Location: UMC 425

Chair(s): Ramesh Malla; Robert Mueller; Kris Zacny; Yunlan (Emma) Zhang

Moderatorss



Ramesh Malla

Professor, Structural Engineering and Applied Mechanics | University of Connecticut, Storrs, CT, U.S.A.



Emma Zhang

Assistant Professor | University of Texas at Austin

ID 819: Comprehensive Characterization of Extra-Terrestrial Regoliths: Role of Raman Imaging

4:00 PM – 4:20 PM

Author(s): Nishant Garg, University of Illinois Urbana-Champaign

The establishment of sustainable human habitats on the Moon and Mars depends on In-Situ Resource Utilization (ISRU) to harvest construction materials from local regolith. Current strategies explore the use of regolith for construction through approaches such as alkali activation and sintering. However, the variability in regolith composition and the lack of detailed phase analysis highlight the need for comprehensive mineralogical studies to predict reaction kinetics and durability. We address this challenge by employing a multi-technique approach involving X-ray Diffraction, SEM-EDS, and Raman Imaging to characterize extra-terrestrial regolith simulants. Specifically, we identify key mineral phases and evaluate their suitability for alkali-activation based on amorphous content and Si/Al ratios. Overall, this work advances the fundamental understanding of extraterrestrial regolith chemistry, facilitating the development of durable infrastructure for planetary exploration.

Speaker



Nishant Garg

Associate Professor | University of Illinois Urbana-Champaign

ID 948: Continuum and Free Molecular Flow Approaches for Determination of Rocket Plume Impingement Loads on Lunar Launch/Landing Pads

4:20 PM – 4:40 PM

Author(s): Sushrut Vaidya, University of Connecticut; Ramesh Malla, University of Connecticut

Establishing a lunar base suitable for long-term human habitation is among the foremost challenges confronting space technologists today. One of the first tasks to be accomplished in order to achieve this goal is the construction of launch/landing pads (LLPs) on the lunar surface, to support and facilitate spacecraft operations associated with lunar missions. The design and construction of a lunar LLP will require determination of various loading effects generated by spacecraft operations, including mechanical and thermal load distributions on the pad due to rocket exhaust plume impingement. Due to the hard vacuum associated with the extremely thin lunar atmosphere, the exhaust plume generated by a spacecraft in the lunar environment is highly underexpanded. Hence, interactions between the highly underexpanded exhaust plume and the LLP surface must be considered in determining the plume impingement-induced loads on the LLP.

A detailed methodology is presented for determination of plume impingement-induced mechanical and thermal loads for lunar LLP design, considering two different models of the flow associated with an impinging plume in a near-vacuum environment. First, a well-established continuum flow-based plume-surface interaction (PSI) theory is verified by determining the plume pressure and temperature distributions on a flat surface, considering laboratory-scale and full-scale rocket nozzles for which results are available in the literature. Next, the equations of free molecular flow theory are verified using published experimental data for a laboratory-scale nozzle, by comparing theoretical predictions and experimental observations of mechanical and thermal load distributions due to plume impingement on a flat surface. Subsequently, the continuum flow-based and free molecular flow-based methodologies are compared by applying both models to predict the LLP loading generated by the plume of a modern, full-scale rocket engine. An approximate method of accounting for different thrust levels in launch versus landing operations is discussed. The advantages and drawbacks of continuum flow-based and free molecular theory-based LLP load calculation approaches are outlined from an engineering design perspective. Finally, an overview of limitations and potential extensions of the methodology is presented. Such analytical flow models, buttressed by appropriate design factors to account for lunar environmental considerations and uncertainties in lunar operations, may serve as important tools in determining plume impingement-induced mechanical and thermal loads for lunar launch/landing pad design.

Speaker



Ramesh Malla

Professor, Structural Engineering and Applied Mechanics | University of Connecticut, Storrs, CT, U.S.A.

ID 998: Internally Actuated Tensegrity Rover for Lunar and Martian Exploration

4:40 PM – 5:00 PM

Author(s): Yitao Jiang, Dartmouth College; Muhao Chen, University of Houston

Tensegrity structures are well suited for planetary rover applications that demand high impact tolerance, compliance, and robustness in extreme and uncertain environments. This paper presents a 3D-printed tensegrity rover concept for lunar and Martian surface exploration, integrating a multi-material additively manufactured outer tensegrity shell with a protected internal payload module. The outer structure provides passive shock absorption, terrain adaptability, and structural resilience, while shielding sensitive components from impact loads and harsh surface interactions. The internal payload is a rigid tetrahedral body housing the power system, sensors, custom electronics, and four motor–winch actuation units. It is suspended within the spherical tensegrity frame by four tensioned cables routed to anchor points on the outer structure. Coordinated adjustment of cable lengths enables three-dimensional repositioning of the payload, shifting the system's center of mass to induce controlled rolling locomotion. Redundant cable tension ensures stable suspension and load redistribution during motion. The proposed architecture demonstrates an internally actuated, cable-driven locomotion strategy that minimizes external moving parts, addressing key challenges in planetary environments such as impact survivability, dust exposure, and mechanical reliability. The presented prototype serves as a scalable experimental platform for advanced 3D-printed tensegrity systems, autonomous robotic exploration, and resilient extraterrestrial mobility concepts.

Speaker



Muhao Chen

Assistant Professor | University of Houston

ID 1005: Architected Design and Autonomous In-Space Assembly of a Large, Lightweight HOEE Starshade Structure

5:00 PM – 5:20 PM

Author(s): Omar Marrey, The University of Texas at Austin, Austin, TX; Andrea Poli, University of Michigan, Ann Arbor, MI; Wei-Chun Lu, University of Michigan, Ann Arbor, MI; Abraham Ramirez, University of Michigan, Ann Arbor, MI; Timothy Filemyr, NASA Goddard Space Flight Center, Greenbelt, MD; Rachel Ticknor, NASA Ames Research Center, Mountain View, CA; Bob McMurray, NASA Ames Research Center, Mountain View, CA; Christine E. Gregg, NASA Ames Research Center, Mountain View, CA; Serife Tol, University of Michigan, Ann Arbor, MI; Othman Oudghiri-Idrissi, The University of Texas at Austin

Future space exploration and exoplanet discovery missions demand structures of unprecedented scale and precision, enabled by modular architectures and autonomous in-space assembly. Supported by NASA's Innovative Advanced Concepts (NIAC) program, this study presents an architected design for a 99-meter-diameter orbiting starshade structure that enables direct imaging and spectroscopic analysis of Earth-like exoplanets around bright stars when paired with a ground-based telescope. The starshade structure functions as an external occulter, suppressing the star light while allowing only the faint light reflected from orbiting planets to be captured and analyzed by the ground telescope, as part of the hybrid observatory for Earth-like exoplanets (HOEE).

The principal structural engineering challenge is achieving ultra-low mass while maintaining high stiffness and millimeter-level dynamic precision to meet stringent optical performance requirements. To address this challenge, a multidisciplinary design framework is developed to examine different unit-cell geometries, material properties, and joint configurations, to optimize key structural and optical performance metrics. The resulting structure consists of three-dimensional rhomboid frame unit cells interconnected by shell members and beam elements. Linear radial tapering and origami-inspired creasing of the shell surfaces are also implemented to enhance the bending stiffness with minimal mass penalty. Using a scaffolding support system and autonomous robotic assembly, the unit cells are deployed in a radial configuration to form the characteristic flower-like starshade geometry.

A comprehensive analysis of the structure's natural frequencies, mode shapes, and the impact of its dynamic response on optical performance is conducted. The results demonstrate a viable design pathway for achieving the precision required for high-resolution exoplanet observations using a large, autonomously assembled modular starshade structure.

Speaker



Othman Oudghiri-Idrissi

Assistant Professor | The University of Texas at Austin

ID 898: Synthetic Digital Twins for Multi-Physics Simulation of Robotic Operations in Complex Unstructured Environments

5:20 PM – 5:40 PM

Author(s): Naveen Kumar Muthumanickam, National Laboratory of the Rockies/NLR (formerly National Renewable Energy Laboratory/NREL)

Robotics has the potential to transform physical labor across a wide range of domains, yet its deployment has remained largely confined to controlled environments such as factories, warehouses, and logistics centers. Expanding robotic operations to complex unstructured environments, including construction sites, disaster zones, natural terrain, and extraterrestrial surfaces, require advanced autonomy, real-time perception, and adaptive decision-making. Physical testing in these environments, or constructing physical replicas for testing, is expensive, hazardous, and difficult to scale. Digital representations offer an alternative, but they often lack the fidelity needed to capture the complexity of real-world conditions. This gap underscores the need for digital twins that can synthetically mimic real-world physics like model terrain, soil interactions, environmental forces, and dynamic robotic behavior for effective training and validation. The Industrialized Construction Innovation (ICI) team at the National Laboratory of the Rockies and the Robotic Space Exploration (RoSE) Lab at the Colorado School of Mines collaborated to develop and test synthetic digital twins for studying multi-physics interactions between robots and unstructured environments. This presentation will provide a high-level overview of this ongoing research, including how simulation tools such as NVIDIA Isaac Sim, Newton, Genesis, and ROS have been used to model and test robotic behavior in synthetic representations of lunar environments. It will also discuss how similar digital twins informed the deployment of robotic systems in real-world pilot studies, including the construction of a scaled energy infrastructure prototype, and how these developments can be extended to support robotic operations in future lunar missions.

Speaker



Naveen Kumar Muthumanickam

Research Engineer - Industrialized and Robotic Construction Innovation | National Laboratory of the Rockies/NLR

ID 793: Deployable Domes for Lunar Construction

5:40 PM – 6:00 PM

Author(s): Devin Young, University of Texas at Austin; Lucas Laughery, Exponent; Yunlan Zhang, University of Texas at Austin; Mike Fiske, Amentum Space Exploration Division

Not all extraterrestrial infrastructure can be stowed in a fairing at the full scale needed later, and not all can be conventionally “stick-built” by robots. Deployable, pressurizable structures are critical to long-term infrastructure development in extraterrestrial environments as a means of providing larger volume while still being stowable and re-usable. These structures can be used for a variety of purposes, from providing life-critical services (i.e., habitats and farming) to manufacturing facilities. Here, we present a design framework for lunar deployable domes which combine a deployable truss mechanism with a membrane, topped by lunar regolith to provide radiation shielding as needed while offsetting loads from pressurization and providing stability. We then present an example application for manufacturing of Lunar Calcium Sulfoaluminate (CSA) cement structural elements, which benefit from partial pressurization (0.6 atm or more).

Speaker



Lucas Laughery

Senior Engineer | Exponent

MS 048: Mechanics and Modeling of Mass Timber Structures and Materials Subjected to Extreme Loads

4:00 PM – 6:00 PM | Location: ECON 13

Chair(s): David Roueche; Mark Weaver; Kadir Sener; Shiling Pei; Christian Viau; Mike Hillman

Moderators



David Roueche

Gottlieb Associate Professor of Civil and Environmental Engineering | Auburn University

ID 507: A Collaborative Mechanical Characterization of Clear Wood Loblolly Pine under Various Load-Rate and Environmental Test Regimes for Advancing High-Fidelity Modeling

4:00 PM – 4:20 PM

Author(s): Ryan Holtzschler, Auburn University; David Roueche, Auburn University; Kadir Sener, Auburn University; Mark Weaver, Karagozian & Case; Marco Ricco, Forest Products Laboratory; Bryan Casillas, US Army Engineering Research and Development Center; James Davidson, Auburn University

High-fidelity models for predicting the performance of mass timber under blast and other extreme loads are dependent on accurate material models. Mass timber is particularly challenging to model because wood is orthotropic and is highly sensitive to environmental and strain rate effects relative to other common building materials. There is a lack of consistent data capturing these effects that is suitable for building accurate material models for wood. This presentation summarizes a multi-institution, multi-scale effort to capture experimental data on the fundamental stress-strain response of clear wood specimens across a range of single- and multi-axis stress states (e.g., tension parallel, compression perpendicular, triaxial compression), environmental conditions (dry, ambient, and wet) and strain rates (quasi-static, intermediate, high).

Testing was conducted by Auburn University, the Forest Products Laboratory, Karagozian & Case (K&C), and the U.S. Army Engineering Research and Development Center (ERDC). All testing was conducted with clear wood loblolly pine specimens sourced from the same cut of a loblolly plantation located in Virginia. Despite the common objectives, the test program details, including the loading equipment, sample sizes, and specimen sizes, were not identical across each institution. Considerable overlap still occurred however, particularly in the quasi-static and intermediate strain rate uniaxial tests. Auburn University tested clear wood samples nominally in accordance with ASTM D143, including tension parallel to grain, compression parallel to grain, and bending tests across quasi-static and intermediate strain rates (up to ~100 s⁻¹) and across dry, ambient, and wet moisture conditions. The Forest Products Laboratory focused on quasi-static tests in accordance with ASTM D143 for tension parallel and perpendicular, compression parallel and perpendicular, and shear parallel to grain. K&C performed uniaxial compression, tension, and shear tests at strain rates ranging from quasi-static to 1000 s⁻¹. ERDC performed quasi-static tri-axial compression tests.

This presentation will summarize the results across the entire test programs and present a comprehensive view of the fundamental wood behavior of loblolly pine that would facilitate high-fidelity modeling. For example, preliminary results suggest that strain rate effects vary by stress state and environmental conditioning. The presentation will also highlight similarities and differences in the results obtained across overlapping portions of the test program, and recommend best practices for similar studies on other wood species.

Speaker



Jack Laws

Auburn University

ID 575: Restoring Load Capacity of Glulam Beam-to-Beam Connections

4:20 PM – 4:40 PM

Author(s): Sardar Malek, University of Victoria; Solomon Rosenberg, University of Victoria; Phalguni Mukhopadhyaya, University of Victoria

The transition to a circular economy in construction is hindered by the lack of validated protocols for the structural reuse of glued-laminated timber (glulam) beams. This is particularly challenging due to damage caused by proprietary beam-to-beam connections. The fastener holes from these connections introduce stress concentrations that limit the material's capacity for reuse. This research experimentally evaluates the effectiveness of epoxy-based restoration in recovering the load-bearing performance and stiffness of previously used glulam connection beam ends. Glulam beam-end specimens were subjected to an initial loading, disassembled, and then reconditioned under three distinct states: (1) no rehabilitation (baseline), (2) partial epoxy filling of holes with connection reinstallation in the same location, and (3) full epoxy filled and cured holes, with the connection moved to a new location. Results demonstrate that epoxy-based rehabilitation significantly improves connection performance. The partially filled and fully filled epoxy samples exhibited significant increases in peak load over the non-rehabilitated baseline. This study shows that epoxy filling can effectively restore the structural integrity and stiffness of glulam members after connection removal, providing a viable pathway for the structural reuse of mass timber products, thereby making a tangible contribution to construction industry sustainability goals.

Speaker



Sardar Malek

Associate Professor | University of Victoria

ID 673: Experimental and Numerical Study of the Shear- and Flexure-Controlled Response of Cross-Laminated Timber Beams Manufactured with Loblolly Pine

4:40 PM – 5:00 PM

Author(s): Blake DiSalvo, Auburn University; David Roueche, Auburn University; Kadir Sener, Auburn University; Erkan Mutlu, Auburn University; James Davidson, Auburn University

One of the major structural advantages of timber in structural applications is its enhanced ability to resist short duration loads, such as those produced by extreme winds, earthquakes, and air blasts. For intermediate and high strain rate loading ($> 70 \text{ } \epsilon/\text{s}$), this effect is typically quantified using Dynamic Increase Factors (DIF), which relate the ultimate capacity or other properties under high strain rates to those measured under quasi-static strain rates. To quantify accurate DIF for Southern Pine mass timber, there is a need for additional testing under quasi-static strain rates, in both flexure-controlled and shear-controlled loading regimes, for improving the predictability of the static response. This study describes an experimental program designed to evaluate stiffness, capacity, and resistance functions for Southern Pine CLT beams under quasi-static testing with the primary objectives of (1) evaluating the accuracy of current analytical methods, specifically PDC-TR 18-02, for estimating the expected stiffness and peak capacity of CLT under one-way bending, (2) evaluating and quantifying any potential size effect factor for improved analytical predictions of shear and flexural capacities, and (3) developing numerical models capable of replicating the linear-elastic and post-peak response.

The experimental program was performed on cross-laminated timber specimens manufactured from No. 2 loblolly pine laminae. The test matrix varied the panel depth (3, 5, 7, and 9 plies), width (12-inch, 24-inch, and 36-inch), shear-span-to-depth (a/d) ratio (2, 2.5, 3, 4, and 5), and loading configuration (3- and 4-point). At least 2 replicates were performed of every test configuration, and a total of 58 tests were performed. All tests were performed with a full suite of physical instrumentation measuring applied force, displacement, and rotation. Additionally, 3D Digital Image Correlation was used to track full displacement and strain fields throughout each test. In combination, these instrumentation facilitated redundant methods for calculating fundamental mechanical properties such as the effective and apparent bending stiffness, shear rigidity, and peak force. Finite element modeling was performed in LS-DYNA using the MAT_143 wood material model. Models employed single-point integrated solid elements with hourglass control to suppress spurious deformation modes.

Results found that the PDC-TR 18-02 provisions (which are intended to predict mean response) generally underestimated the peak strength in both shear- and flexure-controlled failures. A size-effect was apparent, but was non-monotonic and most evident in the 3- and 7-ply specimens. The numerical models displayed promising accuracy. The correlation between FE models and experimental results was strong across all configurations, with initial stiffness predictions particularly accurate. Peak load predictions were generally within 10% of experimental values, with greater deviations occurring in flexure-dominated cases at higher a/d ratios. Ultimately, this study provides a rich dataset with which to calibrate and validate both analytical and finite-element modeling approaches, and recommends potential improvements to existing design provisions. More accurate predictions of the static response will further clarify potential dynamic increase factors for use in designs against extreme loading conditions.

Speaker



David Roueche

Gottlieb Associate Professor of Civil and Environmental Engineering | Auburn University

ID 730: Mechanics-Based Closed-Form Solution for Predicting the Two Way Bending Behavior of Cross-Laminated-Timber Panels

5:00 PM – 5:20 PM

Author(s): Erkan Mutlu, Auburn University; Kadir Sener, Auburn University; David Roueche, Auburn University; Jim Davidson, Auburn University

Wood is inherently orthotropic, and this direction-dependent behavior in cross-laminated timber (CLT) systems, where the grain directions of laminae are alternated between layers, evolves into a more complex mechanical response particularly under two-way plate action. While CLT floor panels provide an efficient load-carrying mechanism, the orthotropic nature makes it difficult to predict two-way response, including stiffness and capacity, trends under concentrated or uniform loads using traditional mechanics-based methods. Existing guidance for two-way action is largely based on yield-line theory developed for reinforced concrete slabs; however, because wood does not exhibit yielding in the same manner, a stress-based limit state is adopted. This study presents a design-oriented solution method that computes two-way load response of CLT panels in closed form and predicts the ultimate load based on the analytically obtained stress and force resultants.

The method transforms CLT layouts into equivalent orthotropic plate properties. The orthotropic plate stiffness matrix is assembled using effective bending rigidities in the major and minor directions. Transverse shear deformation is included in the analysis through effective shear rigidities, treating the plate as a thick plate. The plate deflection field is expressed using a two-dimensional Navier sine series that satisfies simply supported boundary conditions on all four edges. Uniformly distributed loading and a concentrated load applied at the panel center are expanded in the same Fourier basis for forming closed-form relations based on modal amplitudes.

Ultimate load capacity is determined by scaling analytical stress demands until critical limit states are reached. Candidate failure criteria include tension and compression limits in outer laminae and shear limits at locations expected to govern under two-way bending. The load level at which the first limit is met defines analytical capacity.

The proposed approach enables rapid parametric investigation of the effects of span, layup, thickness, and orthotropy ratio by producing full-field deflection and moment maps at low computational cost, and offers an interpretable, complementary mechanics tool to finite element analyses. Comparisons with experimental testing and finite element analyses demonstrate that the formulation captures key stiffness and strength trends and provides a practical mechanics tool for CLT panel evaluation.

Speaker



Erkan Mutlu

Graduate research assistant | Auburn University

ID 111: Reliability-based evaluation of cross-laminated timber (CLT) ballistic resistance for performance prediction and design

5:20 PM – 5:40 PM

Author(s): Juliet Swinea, US Army Engineer Research Development Center; Iris Tien, Georgia Institute of technology; Peter Stynoski, US Army Engineer Research Development Center; Lauren Stewart, Georgia Institute of Technology

Cross-laminated timber (CLT) is a promising sustainable building material for temporary and permanent military applications. Experimental research in the past decade informed design guidance for CLT components against blast loading and forced entry, but formal guidance for CLT systems under ballistic impact is not currently available partly due to inherent uncertainties affecting localized resistance. In this article, we investigate the impact of quasi-static wood material property variability on partial penetration ballistic resistance uncertainty by conducting 61 total ballistic impact experiments on an untested prominent structural species, Douglas Fir (DF). With the DF experimental results in combination with a leveraged CLT ballistic and material property database, we predict and characterize the ballistic resistance of any CLT panel using a defined single penetration depth equation and the computationally inexpensive reliability-based First-Order Second-Moment (FOSM) method. We use this approach to characterize and capture the inherent variability of CLT under ballistic impact, and represent resistance profiles as probabilistic distributions rather than single values. We apply the predictive method at different scales, from DF panel-specific single velocity estimates to full species partial penetration profiles. For each data grouping, the FOSM prediction fully captured within 95% confidence intervals the experimental dataset. Needing only two easily obtained wood material properties, the method provides accurate and robust predictions of the resistance of this variable material under dynamic localized loading. As a result, we argue predicted baseline resistance profiles considering inherent material variability can act as the informed starting point for decision makers to apply situation dependent design safety factors.

Speaker



Lauren Stewart

Georgia Tech

ID 736: Comparative Seismic Response of Full-Scale Tall and Mid-Rise Mass Timber Buildings under Extreme Ground Motions

5:40 PM – 6:00 PM

Author(s): Prashanna Mishra, Colorado State University; John van de Lindt, Colorado State University; Shiling Pei, Colorado State University; Andre Ramos Barbosa, Oregon State University; Arijit Sinha, Oregon State University; Steve Pryor, Simpson Strong Tie; Barbara Simpson, Stanford University; Steven Kontra, KL&A Engineers and Builders; Patricio Uarac, Oregon State University; Morgan Mcbain, Stanford University

Mass timber systems have emerged as viable structural solutions for mid- and high-rise construction due to their sustainability, constructability, and favorable seismic performance. However, the orthotropic and nonlinear behavior of timber materials, combined with the complexity of hybrid energy dissipation and self-centering mechanisms, presents significant challenges for accurate modeling and design under extreme loading conditions. This study investigates the mechanical response and system-level behavior of full-scale mass timber buildings subjected to high-intensity seismic excitation, with an emphasis on implications for modeling and performance-based design.

The research draws on experimental data from two landmark full-scale shake table test programs conducted at the NHERI@UCSD facility: a ten-story mass timber building (NHERI TallWood) and a six-story derivative system (NHERI Converging Design). Although differing in height and lateral force-resisting configurations, both structures were subjected to comparable ground motions, enabling a unique comparative assessment of dynamic response, energy dissipation, and damage evolution under extreme seismic demands. Key response metrics examined include acceleration amplification, floor displacements, interstory drift demands, base shear, and modal response characteristics.

Results highlight the influence of structural configuration, energy dissipation mechanisms, and system redundancy on peak and residual response, as well as on the distribution of damage within the lateral system. Observed behaviors provide valuable experimental benchmarks for validating simplified and advanced numerical modeling approaches for mass timber structures, including nonlinear dynamic analyses and reduced-order representations. The findings also underscore key uncertainties associated with material behavior and connection response under extreme loading. Overall, this work contributes experimental insight to support improved modeling fidelity and more rational design methodologies for mass timber systems subjected to extreme dynamic loads.

Speaker



Prashanna Mishra

Mr. | Colorado State University

Banquet

6:30 PM – 9:00 PM | Location: Limelight - Flatirons 1

<https://www.emi-conference.org/banquet>

Friday, June 05, 2026

Breakfast

7:00 AM – 8:00 AM

Buffet-style breakfast

7:00 AM – 8:00 AM

Light breakfast

7:30 AM – 8:00 AM

Light breakfast will be served until 9am. Foods and drinks are allowed in the Ballroom.

Registration

7:30 AM – 12:00 PM | Location: UMC - Aspen Rooms

Keynote: Quantum algorithms for differential equations: Opportunities and challenges

8:00 AM – 9:00 AM | Location: UMC - Glenn Miller Ballroom

Quantum algorithms for differential equations: Opportunities and challenges

Andrew Childs, Ph.D.

Professor

Department of Computer Science and Interim Director

University of Maryland Institute for Advanced Computer Studies (UMIACS)

Abstract: Quantum computers have the potential to solve certain problems dramatically faster than ordinary classical computers. In particular, quantum algorithms can potentially accelerate the solution of high-dimensional systems of differential equations by representing them using quantum states. However, this approach imposes strong constraints on the problem input and provides limited access to the solution, making it unclear whether it will be advantageous in practice. This talk will review the techniques and prospects for quantum algorithms for linear and nonlinear differential equations, considering both the potential strengths and the known limitations of such approaches.

Biosketch: Andrew Childs is a professor in the Department of Computer Science and interim director of the University of Maryland Institute for Advanced Computer Studies (UMIACS). He was a co-director of QuICS from 2014-2024, and is the director of the NSF Quantum Leap Challenge Institute for Robust Quantum Simulation.

Childs's research interests are in the theory of quantum information processing, especially quantum algorithms. He has explored the computational power of quantum walk, providing an example of exponential speedup, demonstrating computational universality, and constructing algorithms for problems including search and formula evaluation. Childs has also developed fast quantum algorithms for simulating Hamiltonian dynamics. His other areas of interest include quantum query complexity and quantum algorithms for algebraic problems.

Before coming to UMD, Childs was a DuBridge Postdoctoral Scholar at Caltech from 2004-2007 and a faculty member in Combinatorics & Optimization and the Institute for Quantum Computing at the University of Waterloo from 2007-2014. Childs received his doctorate in physics from MIT in 2004.

Speaker



Andrew Childs

Professor | University of Maryland

Moderators



Yida Zhang

Associate Professor | University of Colorado Boulder

Coffee Break

9:00 AM – 9:30 AM | Location: UMC - Aspen Rooms & UMC - 235

MS 001: Smart Sensing and Artificial Intelligence for Advanced Civil Infrastructure Monitoring and Management

9:30 AM – 11:30 AM | Location: HUMN 250

Chair(s): Yuguang Fu; Jian Li; Patrick Sun; Xiao Liang

Moderatorss



Yuguang Fu

Assistant Professor | Nanyang Technological University



Jian Li

Deane E. Ackers Professor | University of Kansas

ID 11: Vision-Based Structural Health Monitoring: A Comparative Analysis of Computer Vision Platforms for Displacement Tracking

9:30 AM – 9:50 AM

Author(s): sahel niyafard, university of connecticut; Alexandra Hain, university of connecticut

This study presents a pilot evaluation of vision-based displacement tracking methods for structural health monitoring (SHM), using a full-scale cantilever test of porcelain railway insulators to benchmark accuracy. The goal is to assess the feasibility of image-based techniques as scalable, non-contact alternatives to traditional displacement sensors in civil infrastructure applications. Four computer vision platforms, MATLAB, Python, Blender, and SynthEyes, were tested across three tracking methods: optical flow (KLT), template matching, and manual marker tracking. These platforms span both proprietary software with associated licensing costs and open-source tools, reflecting a range of accessibility and flexibility. While some, such as Blender and SynthEyes, are widely adopted in animation, film, and robotics, they remain largely unexplored in the context of SHM. High-resolution video recordings were processed to extract displacement data, which were calibrated using physical rulers and compared against ground-truth sensor measurements. Among the methods tested, Python with OpenCV's KLT implementation and SynthEyes yielded the most accurate and consistent results. This work highlights how software selection and algorithm type influence measurement fidelity. By identifying high-performing, accessible platforms, this study lays the groundwork for broader adoption of vision-based methods in SHM. As the first phase of a larger research effort, these findings inform the development of robust, image-based assessment frameworks for long-term monitoring and inspection of civil infrastructure systems.

Speaker



Sahel Niyafard

Graduate Research Assistant | University of Connecticut

ID 100: Self-Deployable AIoT Prototype for Scalable Mobile Sensing

9:50 AM – 10:10 AM

Author(s): Xuewen Yu, Nanyang Technological University; Yuguang Fu, Nanyang Technological University

In recent years, the gradual aging of civil infrastructure and increasing environmental impacts have created an urgent demand for efficient, accurate, and cost-effective large-scale monitoring and management systems or strategies. However, conventional structural health monitoring (SHM) systems are often labour-intensive, time-consuming, and expensive, particularly in terms of system deployment. To address the challenges, this study presents a self-deployable AIoT system prototype named SmartBee that is small, cheap, and agile, enabling autonomous and high-granularity mobile sensing networks. SmartBee is built on the open-source flying platform Bitcraze Crazyflie 2.1+, weighs less than 50g, and is palm-sized. A vision-based autonomous navigation algorithm is implemented and runs aboard the drone to realize obstacle avoidance. Predefined position parameters combined with QR code are utilized to guide the drone to land at designated locations on structural surfaces with a desired orientation. The landing gear is retrofitted with soft material to provide additional sticking force, ensuring firm attachment during measurement. A third-party high-resolution MEME accelerometer is integrated for vibration signal acquisition. Indoor experiments are conducted to validate the performance of the proposed "flyable sensor" system and to assess the quality of the collected data. To the best of the authors' knowledge, this work represents the first demonstration of a drone-based system capable of directly attached vibration measurement, opening new possibilities for mobile, deployable sensing in SHM.

Speaker



Yuguang Fu

Assistant Professor | Nanyang Technological University

ID 285: Monitoring and Prediction of Cracking Behavior and Reinforcement Response in Composite-concrete Systems with DFOS and Deep Learning

10:10 AM – 10:30 AM

Author(s): Sike Wang, Purdue University; Junyi Duan, Purdue University; Yizhou Lin, Purdue University; Huaixiao Yan, Purdue University; Xingyu Wang, North Dakota State University; Xiaoli Xiong, Purdue University; Ying Huang, North Dakota State University; Shanyue Guan, Purdue University; Chengcheng Tao, Purdue University

This study aims to develop a smart structure health monitoring and prediction pipeline for increasing the inner sensing ability of composite-concrete systems. Through embedding distributed fiber optic sensing into the composite reinforcement, the critical strain distribution could be monitored in real-time. A three-point bending test was conducted in a composite beam to validate the accuracy of the strain-sensing system and achieve a strong correlation to the finite element analysis (FEA) model. Furthermore, a real-time digital twin framework is developed to realize the visualization of strain distribution and damage propagation processes within the interior structure. In addition to detecting the strain change in the composite-concrete system, the cracking patterns, which are highly related to the safety of composite-concrete structures, are analyzed in the study. It demonstrates that the high-tension area in the composite refinement is highly related to the surface cracking of the structure. Utilizing this phenomenon, a deep learning-based method is developed to identify the reinforcement condition in terms of non-contact measurement of strain. The framework contained two stages: first, using crack pattern and strain data obtained from FEA simulation to train the Kolmogorov–Arnold network (KAN)-based convolutional neural network (CNN) strain prediction model. The KAN-based CNN has a new branch in the convolution calculation, which replaces the traditional activation function with learnable radial basis functions for a fast realization of KAN. Subsequently, surface cracking images of the composite-concrete beam are segmented by you only look once v11, and the segmentation results are matched with the simulated cracking patterns by the intersection over union to generate the input of the strain prediction model. The proposed method achieves an average R^2 of 0.713 in the three-bending test of an FRP-concrete beam, and the KAN-based CNN shows a significant improvement compared to the default CNN. Lastly, several case studies, including concrete pavement, bridge grinders, and railroad sleepers, are performed to illustrate the applicability of the proposed method in infrastructure monitoring.

Speaker



Sike Wang

Ph.D. Student | Purdue University

ID 308: Environmental Compensation for Long-Term Fatigue Crack Monitoring Using Wireless Large-Area Strain Sensors

10:30 AM – 10:50 AM

Author(s): Mona Shaheen, The University of Kansas; Jian Li, The University of Kansas; William Collins, The University of Kansas; Caroline Bennett, The University of Kansas; Simon Laflamme, Iowa State University

This research investigates the effects of environmental variability on long-term fatigue crack monitoring of steel bridges using a wireless network of large-area strain sensors. The sensing system employs soft elastomeric capacitors (SECs), which can cover large structural surfaces and measure localized strain changes associated with fatigue crack activity. While SECs are well suited for distributed structural health monitoring, their long-term deployment is challenged by environmental effects, particularly temperature fluctuations. Changes in ambient temperature influence both the global structural response and the sensor's intrinsic output, leading to biased estimates of the crack growth index (CGI). This challenge is especially pronounced in long-term field deployments, where gradual temperature variations can obscure damage-related strain signals and compromise crack assessment accuracy.

To address this challenge, this study integrates long-term field data analysis, numerical modeling, and laboratory experiments to quantify temperature-induced effects in both bridge structures and SECs. Wireless strain data collected from a steel highway bridge are analyzed together with environmental measurements to identify correlations between CGI variations and ambient temperature. Numerical simulations are performed to characterize thermally induced strain responses in steel bridge components under varying temperature conditions and in the absence of crack growth, enabling separation of temperature-driven strain from damage-related signatures. Laboratory experiments are performed to evaluate the temperature sensitivity of SECs and inform sensor-level compensation. Based on these results, a temperature compensation strategy is developed and is incorporated into an existing fatigue crack monitoring algorithm based on time-frequency analysis of traffic-induced strain responses. Validation using real-world monitoring data demonstrates improved stability and accuracy of the compensated CGI under variable environmental conditions. The findings enhance the reliability of long-term fatigue crack monitoring and support the practical deployment of wireless large-area strain sensing systems for fatigue crack monitoring of steel bridges and informed infrastructure maintenance decision-making.

Speaker



Mona Shaheen

The University of Kansas

ID 451: Acoustic Emission Source Localization in Concrete Structures using Modified Stockwell Transform-based CNN Architecture

10:50 AM – 11:10 AM

Author(s): JONGHOON WEON, Department of Architecture, College of Engineering, Seoul National University, Seoul, Republic of Korea; Robin Eunju Kim, Department of Architecture, College of Engineering, Seoul National University, Seoul, Republic of Korea

Early detection of structural damage is critical for ensuring the safety and serviceability of civil infrastructure. Acoustic emission (AE) sensors have been investigated with its capabilities for detecting and localizing damages at their early phases. Conventional AE localization methods use physics-based approaches such as time difference of arrival (TDOA) assuming that the signal undergoes homogeneous media at constant wave velocity. These assumptions may not be valid for heterogeneous materials such as concrete, especially in the presence of reinforcements. In practice, the AE signals experience complex wave propagation and significant attenuation resulting large localization errors in practical. To overcome such limitations, recent studies have applied to AE source localization using time–frequency representations. The studies showed that AE source localization accuracy in heterogeneous concrete is highly sensitive to the selection of time-frequency representation as both the time and frequency dependent behavior must be preserved. For example, Continuous wavelet transform (CWT) can adjust time–frequency resolution through wavelet and scale selection, but they rely on the selected mother wavelet. In contrast, the Modified Stockwell Transform (MST) provides a Fourier-based, phase-preserving representation that encodes physically meaningful quantities such as spectral energy and arrival-time information, while also affording flexible control of time–frequency resolution. These features make the representation less dependent on the waveform shape and more robust to signal variability. Thus, this study proposes a framework for AE source localization adopting MST. Herein, a Convolutional Neural Network (CNN) is used to train the MST transformed signal. To validate the framework, a laboratory-scale reinforced concrete (RC) beam specimen (4.2m long) was fabricated and eight AE sensors were installed in a three-dimensional configuration to capture wave propagation from different spatial directions. Then, artificial AE events were generated using pencil lead break (PLB) tests at specified locations. Each recorded waveform was transformed into an MST-based time–frequency spectrogram, which was then used as input to train a CNN regression model for directly predicting the three-dimensional source coordinates of AE events. The proposed framework achieved a mean 3D Euclidean distance error of 3.43 mm on the training set and 6.40 mm on the validation set, demonstrating stable source localization performance in heterogeneous concrete. This indicates that AE source locations can be reliably estimated even in non-uniform reinforced concrete environments and that the proposed framework provides a practical basis for application to AE signals generated by actual crack formation. The authors are undergoing future extension to apply the proposed framework for the actual crack-induced AE signals.

Speaker



Jonghoon Weon

Master's Student | Seoul National University

ID 691: Three-Dimensional Crack Length Measurement on Cylindrical Bridge Columns Using Vision-Based Reconstruction

11:10 AM – 11:30 AM

Author(s): Zuoxu Wang, Texas A&M University; Xiao Liang, Texas A&M University

Accurate crack length measurement is essential for evaluating the condition of bridge structures and supporting structural health monitoring and maintenance decision-making. Recent advances in computer vision have enabled automated crack detection from images; however, most existing methods estimate crack length directly in two-dimensional image space. While effective for planar surfaces, such approaches become unreliable when applied to curved structural components, particularly cylindrical bridge columns. Surface curvature, perspective distortion, and out-of-plane crack geometry can lead to systematic underestimation of crack length and reduce the physical interpretability of image-based measurements.

This paper presents a three-dimensional crack length measurement framework based on vision-based scene reconstruction. Monocular images of a cylindrical bridge column are first used to reconstruct a dense three-dimensional point cloud representation of the structure using a neural reconstruction approach. Crack regions are identified in the image domain and subsequently projected into the reconstructed three-dimensional space, yielding a crack-specific point cloud embedded on the column surface. To enable physically meaningful and repeatable measurement, the reconstructed column geometry is aligned to a canonical coordinate system and scaled to real-world dimensions. Leveraging the inherent cylindrical geometry of bridge columns, the crack point cloud is parameterized and unwrapped into a surface-based coordinate representation that preserves geodesic distances along the column surface.

Crack length is measured directly in three-dimensional metric space through a robust centerline extraction process applied to the unwrapped crack representation. This procedure mitigates the effects of reconstruction noise, point cloud sparsity, and crack thickness, allowing the full spatial extent of cracks to be captured, including cracks that curve around the column circumference or span multiple viewpoints. Unlike conventional image-based approaches, the proposed method accounts for surface curvature and three-dimensional geometry, providing a more physically consistent measure of crack length.

Preliminary results on cylindrical bridge columns demonstrate that the proposed framework produces crack length measurements that are more accurate and stable than two-dimensional image-based estimates. In particular, the method reduces underestimation errors associated with curved surfaces and enables direct interpretation of crack length in real-world units. Ongoing work focuses on improving robustness to reconstruction drift and partial surface coverage, as well as validating the proposed approach against ground-truth measurements obtained from controlled experiments and field inspections. The proposed framework highlights the importance of three-dimensional geometric reasoning for crack quantification and supports the use of vision-based reconstruction techniques for structural health monitoring of curved bridge components.

Speaker



Zuoxuw Wang

PH.D Student | Texas A&M University

MS 012: Objective Resilience: Advancing Multi-Hazard Physical-Socio-Economic Community Resilience using Physics- and AI-based Modeling and Digital Technologies

9:30 AM – 11:30 AM | Location: HUMN 135

Chair(s): Omar Nofal; Milad Roohi; Yousef Darestani; Lisa Wang

Moderatorss



Lisa Wang

Profes | Old Dominion University



Omar Nofal

Assistant Professor | Florida International University

ID 20: Uncertainty-Aware Deep Regression Framework for Hurricane-Induced Wind Impacts on the Building Envelope

9:30 AM – 9:50 AM

Author(s): Ahmed. A Ewis, Florida International University; Omar Nofal, Florida International University

Hurricanes severely impact coastal communities, disrupting social and economic systems and causing widespread physical damage. Rapid post-disaster assessments are critical for effective emergency response and recovery, yet traditional on-site evaluations are often slow and resource-intensive, delaying critical decisions. Recent advances in machine learning offer faster, automated alternatives by leveraging historical disaster data to predict damage in near real time. This study develops a deep learning regression framework for assessing damage to individual building components across a community using geo-coded post-disaster imagery. The model employs transfer learning, combining a convolutional neural network with a fully connected neural network to optimize predictive performance. Uncertainty Prediction is quantified using Monte Carlo dropout and bootstrapping, yielding confidence intervals for each estimate. The framework is trained and evaluated with imagery from Hurricane Harvey (2017), using five images per building. Results show that both methods achieve comparable predictive accuracy; however, bootstrapping provides a more reliable representation of uncertainty, albeit with increased computational demands. This work demonstrates the potential of deep learning models not only to accelerate damage assessment but also to provide uncertainty-informed outputs that support more reliable decision-making in disaster response and resilience planning.

Speaker



Ahmed A. Ewis

Research Assistant | Florida International University

ID 22: National-level Resilience-Informed Risk Factor: Building-Level Generalized Risk Factor for Buildings in the US

9:50 AM – 10:10 AM

Author(s): Ahmed. A Ewis, Florida International University; Omar Nofal, Florida International University

Flooding—both coastal and inland—affects multiple U.S. communities each year, causing significant impacts on the built environment and long-term socio-economic disruption. To enhance proactive risk mitigation, this study develops a generalized, scalable framework for building-level resilience-informed flood risk assessment. The approach integrates FEMA National Flood Hazard Layer, Fragility-based vulnerability functions, social vulnerability indices, and community resilience factors into a single composite metric representing each building's relative risk. A generalized geospatial algorithm was developed to generate coastal and inland flood hazard maps for any U.S. community based on FEMA's National Flood Hazard Layer (NFHL). Building-specific attributes from the National Structures Inventory (NSI) were used to map a portfolio of minimal flood archetypes and their flood depth fragility and loss functions. This allowed to compute probabilistic physical damage and the corresponding flood losses for each building. Social vulnerability and resilience indices are incorporated from FEMA's National Risk Index (NRI) to account for community-level adaptive capacity and unequal social burdens. These components are integrated into a Resilience-Informed Risk Factor (RIRF), a single numerical index describing each building's overall flood risk within its community context. Finally, machine-learning classification techniques are applied to group properties into risk-based categories, enabling prioritization for mitigation, planning, and investment. The datasets used for the proposed method (NFHL, NSI, NRI) are publicly available nationwide, and the methodology is fully scalable at the national level.

Speaker



Ahmed A. Ewis

Research Assistant | Florida International University

ID 168: Optimal deterioration management under partial observability via reinforcement learning and system reliability-based resilience analysis

10:10 AM – 10:30 AM

Author(s): Jinseo Park, Seoul National University; Taeyong Kim, Yonsei University; junho song, Seoul National University

As urban areas develop, expand, and gradually mature, priorities naturally shift from constructing new infrastructure to ensuring the long-term performance of existing structural systems. In this context, system performance assessment extends beyond point-in-time safety by evaluating the ability of structural systems to withstand disruptions, maintain essential performance, and recover over time, even in the presence of deterioration. To ensure the safety of deteriorating structures from a disaster resilience perspective, it is necessary to explicitly account for the changes in structural condition and performance uncertainty over time. However, due to the highly stochastic nature of structural deterioration, its true condition is only partially observed through sparse and noisy inspection data. As a result, predicting degradation trajectories, quantifying resilience loss, and planning timely interventions with confidence become challenging. To address these challenges, we propose a deterioration management framework that integrates deep reinforcement learning (DRL) with resilience analysis for optimal repair and retrofitting decisions under uncertainty. In the proposed framework, the deterioration management problem is formulated as a partially observable Markov decision process (POMDP), in which DRL is employed to identify optimal retrofit actions for structural components under imperfect information. Compared with traditional exact or approximate POMDP solution methods, DRL offers a flexible and scalable way to implicitly learn hidden deterioration dynamics from partially observed data. Furthermore, a system reliability-based disaster resilience assessment is embedded into the reward function, enabling quantitative characterization of structural resilience and informing decisions on the timing and selection of retrofit actions. Numerical examples demonstrate that the proposed approach enables efficient, adaptive, and resilience-informed management across diverse deterioration and disruption scenarios. Incorporating a system reliability-based resilience measure into the RL allows for transparent, quantitative trade-offs between cost and resilience performance. The proposed framework facilitates the objective communication of management priorities and supports the development of resilience-oriented maintenance and retrofitting guidelines for aging infrastructure.

Speaker



Jinseo Park

Ph.D. Student | Seoul National University

ID 215: InsurAgent: A Large Language Model-Empowered Agent for Simulating Individual Flood Insurance Decisions

10:30 AM – 10:50 AM

Author(s): Ziheng Geng, University of Miami; Minghui Cheng, University of Miami

Flood insurance is a critical instrument for enhancing community resilience by mitigating household-level economic losses from flood hazards. However, despite increasing flood risk under climate change, participation rates among at-risk populations in the United States remain persistently low. Addressing this gap requires modeling frameworks that can realistically capture the behavioral mechanisms underlying individual insurance decisions under uncertainty. This study introduces InsurAgent, a large language model (LLM)-empowered agent for simulating individual behavior in flood insurance purchases. A benchmark dataset is first constructed from empirical survey data to capture insurance purchase probabilities across key factors. Systematic evaluation reveals that while LLMs demonstrate qualitative awareness of behavioral drivers, they struggle to reliably estimate quantitative purchase probabilities. To overcome this limitation, InsurAgent integrates five modular components: perception, retrieval, reasoning, action, and memory. Specifically, a retrieval-augmented generation (RAG) module grounds decision-making in empirical evidence, enabling accurate estimation of marginal and bivariate probabilities. The reasoning module leverages LLM common sense to extrapolate beyond retrieved data, capturing contextual information that is difficult to formalize in conventional statistical models. The memory module supports temporal consistency, allowing simulation of evolving insurance decisions over an individual life course.

Speaker



Ziheng Geng

Mr. | University of Miami

ID 633: Trustworthy AI for Ensuring High-Fidelity Infrastructure Data to Support Flood Resilience in Coastal Communities

10:50 AM – 11:10 AM

Author(s): Jinyuan Xie, Old Dominion University; Wanting (Lisa) Wang, Old Dominion University; Corey Holden, Old Dominion University; Lusi Li, Old Dominion University; Yin-Hsuen Chen, Old Dominion University; George M. Mcleod, Old Dominion University

High-fidelity assessments of coastal resilience capture the full chain of consequences resulting from hazard-induced infrastructure damage across socio-economic and environmental domains. These assessments are essential for advancing analytical capabilities and enabling researchers to develop comprehensive resilience strategies. A key prerequisite for such assessments is the availability of high-resolution datasets. While current open-source building datasets have made significant progress in terms of accessibility and usability, their accuracy remains constrained by incomplete data, limited attribute information, and challenges inherent in multi-source data fusion. To mitigate these limitations, we apply artificial intelligence (AI)-based imputation and classification methods that not only infer missing attributes from weighted similarities among structurally and spatially related buildings but also enhance data consistency across heterogeneous sources. This study uses Norfolk, Virginia as a testbed impacted by flooding hazard scenarios. Two rounds of field and virtual reconnaissance will be conducted on a large set of buildings, categorized by discrepancy groups. These rounds will be used to diagnose systematic mismatches between open-source datasets and ground conditions for key structural features and to further validate the resulting AI-enhanced, high-resolution building dataset. This methodology is broadly transferable to communities facing data accuracy and completeness challenges, enabling high-resolution flood-resilience analysis and decision-support for stakeholders, researchers, and practitioners.

Speaker



Jinyuan Xie

Graduate Student | Old Dominion University

ID 240: An Adaptive Optimization Framework for Life-Cycle Resilience Enhancement of Coastal Power Distribution Systems

11:10 AM – 11:30 AM

Author(s): Amir Mohammad Rabbani, Michigan Technological University; Saeed Sohrabi, Michigan Technological University; Yousef Darestani, Michigan Technological University

Aging coastal power distribution systems face frequent power outages due to aging and extreme wind hazards. Improving the long-term resilience of coastal distribution system requires a strategic, coordinated approach within its lifecycle that considers the costs/budget and benefits of proactive investments to increase the reliability of physical components and reactive or responsive actions to speed up the recovery efforts. The existing literature offers data-driven and physics-based optimization frameworks to enhance the life cycle resilience of power systems. However, most of these models are computationally inefficient. Recently, Deep Reinforcement Learning (DRL) has been implemented to efficiently strengthen the reliability of power distribution system, but to this date there is no comprehensive study that examines and combines various proactive and reactive efforts into a comprehensive optimization framework. Furthermore, models that consider the evolving nature of the distribution system within the optimization are still lacking.

To address these shortcomings, this study proposes an integrated adaptive approach to manage the long-term resilience of coastal power distribution systems through hardening approaches along with reactive operational recovery actions. For this purpose, a DRL algorithm is adopted within a Sequential Monte Carlo (SMC) simulation to adaptively optimize the proactive replacement of different types of utility poles (wood and prestressed concrete) for a multi decade planning period. The DRL agent learns policies and adapts based on prior observations from SMC to enhance the overall resilience of the distribution system in addition to meeting annual and total capital expenditure limitations.

System resilience is quantified by a time-dependent functionality metric to assess performance degradation and recovery after an event. In addition to long-term proactive investment decisions, the framework incorporates operational expenditure associated with post-event restoration activities so that budget constraints and system resilience can be considered within a single optimization framework. Numerical simulation conducted on a representative coastal distribution network compares the proposed DRL-based framework with conventional scenario-based approaches, demonstrating its superior performance in improving long-term system resilience while satisfying budget constraints. The proposed framework is flexible and has been developed to include future control mechanisms including dynamic restoration and resource management as part of a unified framework for adaptive optimization of resilience of coastal power distribution systems.

Speaker



Amir Rabbani

PhD student | Michigan Technological University

MS 016: Decision-making towards resilience on complex, uncertain, and evolving socio-physical systems

9:30 AM – 11:30 AM | Location: HUMN 125

Chair(s): Raul Rincon; Jamie E. Padgett; Mauricio Sanchez-Silva; Leonardo Duenas- Osorio; Dan M. Frangopol

Moderators



Raul Rincon

Incoming Assistant Professor | University of Colorado Boulder

ID 29: Adaptive Digital Twin Framework for Online Fragility Modeling

9:30 AM – 9:50 AM

Author(s): Abdullah Braik, Texas A&M University; Maria Koliou, Texas A&M University

Natural hazards inflict extensive and often catastrophic damage on buildings and critical infrastructure, with consequences that extend far beyond direct physical losses to hinder long-term recovery and compromise overall community resilience. Prior to a hazard event, engineering-based vulnerability modeling supports mitigation, planning, and preparedness. After a disaster, sensing technologies supply rapid, multi-fidelity damage evidence. Despite their shared objectives, predictive vulnerability modeling and post-event sensing have evolved largely as isolated research domains. This separation limits post-event adaptability and weakens early disaster-management decisions, particularly when actual hazard conditions deviate from pre-event assumptions and when observational data become available incrementally rather than simultaneously. To address this gap, this study introduces an adaptive disaster-management digital twin framework that seamlessly integrates pre-event vulnerability forecasts with real-time, multi-fidelity damage observations. The framework continuously updates structural fragility as new data arrives, enabling dynamic correction of biased prior assumptions while rigorously quantifying uncertainty. The methodology is grounded in analytical statistical modeling and employs Bayesian updating to propagate uncertainty. The digital twin framework is validated using the 2011 Joplin tornado disaster case study, where initial fragility estimates are updated incrementally through computer-vision-derived damage probabilities of varying fidelity. Results demonstrate the framework's ability to effectively reduce prior bias, propagate observational information, and produce uncertainty-aware damage estimates that enhance real-time situational awareness. By adapting predictions to emerging evidence while quantifying uncertainty, the proposed digital twin framework strengthens early disaster-management decision-making, offering faster, more robust, and more resource-efficient response strategies.

Speaker



Abdullah Braik

Dr. | Texas A&M University

ID 424: Expected Avoided Loss-Based ROI Analysis to Support Flood Protection Optimization Under Deep Uncertainty

9:50 AM – 10:10 AM

Author(s): Gwyneth Nolde, New York University, Tandon School of Engineering, Department of Mechanical and Aerospace Engineering; Yuki Miura, New York University, Tandon School of Engineering, Department of Mechanical and Aerospace Engineering

Evaluating the economic feasibility or optimality of a climate resilience investment requires accounting for uncertainty in hazard occurrence, population exposure, and infrastructure performance. Given limited resources to support large-scale projects, it is important to optimize resilience strategies where possible in order to maximise coverage, minimize expense, and make the case for investments that are effective both now and in the future. This work builds on an existing simulation-based, return on investment (ROI) optimization framework (Miura et al, 2021b) for coastal flood protection by explicitly incorporating uncertainty across multiple interacting components of flood risk. Candidate protection strategies for any computational domain or scope are evaluated using large ensembles of synthetic coastal storm events, simulated using GIS-based subdivision redistribution (GISSR) methodology (Miura et al, 2021a). For each event, flood impacts are evaluated under baseline and protected conditions, and total losses are computed by combining direct flood damages with indirect losses that arise from interdependent urban infrastructure and systems.

In the proposed framework, additional types of uncertainty are introduced to account for changes in population distribution, population exposure, and technology cost. While overtopping is resolved explicitly in GISSR simulations, failure of protective infrastructure (e.g., floodwalls) is represented probabilistically, allowing for partial or complete failure under extreme loading conditions. Consequences of failure on the population behind the infrastructure are accounted for in damage assessment. Modeling of cascading impacts through interdependent infrastructure is also expanded on in the proposed framework to capture how local damage can have network-wide impacts in complex urban environments like New York City. A single avoided loss metric is computed for each strategy as the expected reduction in total loss, relative to a no-intervention baseline, which is aggregated across the storm ensemble. This avoided loss is compared to implementation and lifecycle costs, producing an ROI metric that reflects the combined effects of hazard variability, cascading impacts, and infrastructure reliability. Additional social and environmental co-benefit metrics are reported to capture impacts such as changes to public space usability, implications for urban environmental quality (e.g., green space or waterfront access), and multi-hazard protection. While these co-benefits are typically evaluated separately from cost-benefit analysis, they are considered here alongside financial metrics to support a more comprehensive comparison of climate resilience strategies.

By incorporating uncertainty throughout the simulation ensemble, this framework supports robust comparison and optimization of resilience investments in unknown future conditions, and highlights how rare but high-consequence failure events can affect expected avoided losses and subsequent ROI estimates. The presentation will describe both the general framework and a detailed case study. New York City, given its high exposure to coastal hazards and the complex interdependencies among its infrastructure systems, is used as a testbed to demonstrate the proposed ROI and optimization framework. Future work will demonstrate the framework's flexibility with respect to domain scale and geography by applying it to larger and more varied environments.

Speaker



Yuki Miura

Assistant Professor | New York University

ID 107: Supporting Decision-Making for Resilience of Coastal Communities under Earthquake-Tsunami Cascading Hazards

10:10 AM – 10:30 AM

Author(s): Mitsuyoshi Akiyama, Waseda University; Dan Frangopol, Lehigh University and University of Colorado Boulder; Ravi Thapa, Waseda University

Coastal communities exposed to megathrust earthquakes are subject to cascading hazards in which strong ground motions are followed by tsunamis within a limited time window. Enhancing resilience under such conditions requires decision-making that accounts for complex interactions among physical infrastructure systems and human activities, rather than treating safety, evacuation, and recovery as isolated issues. This study presents a socio-physical modeling framework that supports resilience-oriented decision-making for coastal communities subjected to coupled earthquake-tsunami hazards, with particular emphasis on human safety and infrastructure recovery.

The proposed framework integrates three interdependent components: (i) probabilistic assessment of seismic and tsunami hazards with spatial correlation, (ii) time-dependent functionality of interdependent infrastructure systems, and (iii) human evacuation behavior under uncertainty. The physical system is represented by road network and disaster waste disposal systems, whose functionalities deteriorate and recover over time due to damage to bridges and processing facilities. The socio component is captured through evacuation behavior, congestion effects, disaster education, and institutional constraints that influence emergency response and recovery processes. By embedding these elements in a unified probabilistic framework, resilience is evaluated using complementary metrics, including evacuation failure probability, casualty risk, network connectivity, and recovery time.

Rather than prescribing optimal actions, the framework is designed to support decision-making by enabling quantitative comparison of alternative resilience strategies under uncertainty. These strategies include seismic retrofitting of critical bridges, placement of tsunami evacuation towers, enhancement of waste processing capacity, and investment in disaster education. Monte Carlo simulation is employed to propagate uncertainties associated with hazard intensities, structural fragility, restoration processes, and human behavior, allowing trade-offs among competing objectives, such as life safety, recovery speed, and resource allocation, to be examined on a common probabilistic basis.

Application to a representative coastal community exposed to the Nankai Trough earthquake scenario demonstrates that measures focusing on a single aspect of the system may be insufficient when cascading effects and interdependencies are considered. The results highlight that balanced combinations of hard countermeasures and soft interventions can achieve greater resilience than isolated actions, and that the effectiveness of each measure depends strongly on its interaction with other socio-physical components. By explicitly linking human consequences with infrastructure performance and recovery processes, the proposed framework provides decision-relevant insights for planners and policymakers facing complex, uncertain, and evolving disaster risk environments.

Speaker



Mitsuyoshi Akiyama

Professor | Waseda University

ID 122: Life-Cycle Multi-Objective Optimization and Decision-Making for Sustainable and Resilient Asphalt Pavement Systems

10:30 AM – 10:50 AM

Author(s): JiYu Xin, Shenzhen University; Mitsuyoshi Akiyama, Waseda University; Dan Frangopol, Lehigh University and University of Colorado Boulder

Research on the life-cycle performance of asphalt pavement, including modeling, analysis, prediction, design, maintenance, monitoring, optimization, and management, has advanced significantly over the past decades. Life-cycle management of asphalt pavements inherently involves multiple conflicting objectives, including structural reliability, agency and user costs, sustainability, resilience to extreme events, and time-variant life-cycle performance. Decisions related to design alternatives, maintenance and rehabilitation strategies, inspection planning, and cost allocation should therefore be formulated within a probabilistic life-cycle multi-objective optimization framework. Such a framework enables decision-makers to quantify trade-offs among objectives, evaluate the long-term effectiveness of different strategies, and identify optimal solutions under uncertainty.

This paper presents a comprehensive and critical review of state-of-the-art research on asphalt pavement life-cycle analysis, with particular emphasis on how multi-objective optimization frameworks support decision-making under uncertainty. The sources and characteristics of two fundamental types of uncertainty, i.e., (a) aleatory uncertainty arising from inherent variability in traffic loading, materials, structural, and environmental conditions, and (b) epistemic uncertainty associated with limited knowledge, modeling assumptions, and data scarcity, are systematically identified across different life-cycle phases. Advances in distress and condition indicators, performance prediction models, reliability and risk assessment methods, life-cycle cost analysis, sustainability metrics, and resilience evaluation are reviewed in an integrated manner, emphasizing their roles in supporting life-cycle decision processes. Furthermore, probabilistic optimization methodologies applicable to asphalt pavement systems are synthesized, including reliability-based optimization, risk-informed decision-making, multi-objective optimization algorithms, and life-cycle approaches.

Particular attention is given to how these methods accommodate multiple performance indicators, while accounting for time-dependent deterioration, maintenance actions, and the propagation of uncertainty across the pavement life-cycle. Representative examples are provided to demonstrate how in-service asphalt pavements can be optimally maintained by balancing risk and sustainability, using deep learning models trained on data from the Long-Term Pavement Performance (LTPP) program. Finally, the paper discusses current challenges and emerging trends in life-cycle pavement management, including data-driven and machine learning-assisted optimization, digital twin-enabled decision support, and the integration of sustainability and resilience objectives into unified optimization frameworks. These developments are expected to play a critical role in advancing intelligent, adaptive, and risk-informed life-cycle management strategies for asphalt pavement systems.

Speaker



JiYu Xin

Assistant Professor | Shenzhen University

ID 302: Spatio-temporal probabilistic characterization of extreme rainfall events towards flood risk reduction in dense urban environments

10:50 AM – 11:10 AM

Author(s): Antonios Lyras, Columbia University; George Deodatis, Columbia University

A methodology is proposed for establishing the spatio-temporal probabilistic characteristics of extreme rainfall events, including their major propagation characteristics, through the computation of their empirical frequency-wavenumber (F-K) spectrum. The event is modelled as a non-Gaussian stochastic wave in two spatial dimensions and time. After the F-K spectrum is computed by applying the appropriate three-dimensional Fourier transform on the observed rainfall field data, it is translated into the corresponding "Slowness" function, utilizing a methodology first developed to analyze propagating earthquake waves and determine their epicenter and propagation direction/velocity (Aki & Richards, 1980). More specifically, this framework translates each point in the three-dimensional F-K spectrum, representing a monochromatic wave component of the rainfall field, into a point in the two-dimensional Slowness plane, where the angle between that point and the positive y semi-axis indicates the azimuth of propagation of that wave, while the inverse of the distance between the point and the origin is equal to its velocity. In that way, it is possible to determine the propagation characteristics of the rainfall field's dominant components (i.e. that have the most power). This framework is put to the test using data from a recorded extreme rainfall event that occurred in the Gard region of southern France in 2002 (Bonnifait et al., 2009). The analyzed rainfall field covers a 50 km x 50 km area and spans an 11-hour period, with a spatial resolution of 1 km x 1km and a temporal resolution of 5 minutes, resulting in 327,500 total data points. Our analysis identified the frequency-wave number content of this event and its major propagation characteristics. An assumption was then made that the rainfall field is non-Gaussian, stationary, and homogeneous. The stationarity and homogeneity assumptions can be relaxed in the future. Based on the established F-K spectrum of the field and its empirical probability density function, sample functions of the rain field were then generated in a Monte Carlo simulation approach, fully reflecting its target probabilistic characteristics. These generated sample rain fields can be used for flood risk analysis and reduction in dense urban areas.

Full references:

Aki, K., & Richards, P. G. (1980). Quantitative Seismology: Theory and Methods. San Francisco: W. H. Freeman and Company.

Bonnifait, L., Delrieu, G., Le Lay, M., Boudevillain, B., Masson, A., Belleudy, P., Gaume, E., & Saulnier, G.-M. (2009). Distributed hydrologic and hydraulic modelling with radar rainfall input: Reconstruction of the 8–9 September 2002 catastrophic flood event in the Gard region, France. *Advances in Water Resources*, 32, 1077–1089.

Speaker



Antonis Lyras

PhD student | Columbia University

MS 030: Physics-based data-driven modeling and uncertainty quantification in computational science and engineering

9:30 AM – 11:30 AM | Location: HUMN 1B50

Chair(s): Bahador Bahmani; Ramin Bostanabad; Johann Guilleminot; Michael Shields; Wei Chen; Lori Graham Brady

Moderators



Bahador Bahmani

Assistant Professor | Northwestern University

ID 136: Reinforcement Learning for Active Solution Operators of Nonlinear Systems

9:30 AM – 9:50 AM

Author(s): Jichuan Tang, University of Notre Dame; Patrick Brewick, University of Notre Dame

Using surrogate models to address real-world scientific problems in complex environments has attracted growing interest within the engineering community for a variety of nonlinear and dynamical applications. Surrogate models are typically created from numerous simulated realizations of a given computational or numerical model. Thus, one of the fundamental challenges for creating surrogates lies in sample efficiency, specifically, determining which model instances maximize surrogate performance. Active learning (AL) alleviates sample selection efforts by strategically selecting the most informative data samples when training a surrogate. The need to discover such informative or extreme samples arises from the expansive parametric space typically encountered with dynamical systems, which are governed by partial differential equations (PDEs), and the necessity of performing multi-parameter optimization across diverse properties.

This study reformulates AL from the perspective of stream-based sequential learning within a Markov decision process. Further, this work introduces a versatile paradigm that leverages reinforcement learning (RL) to guide training sample selection for neural PDE surrogate modeling in high-dimensional parametric spaces. We benchmark the performance of the proposed RL-based agent against baseline AL algorithms on both time-independent and time-dependent PDEs. In addition, we present analyses of error distributions, data variance and reusability, as well as ablation studies examining the impact of different RL design choices. The proposed method advances the state-of-the-art in efficient sampling for training neural operators and solving PDEs. Moreover, the framework's flexibility and efficiency make it broadly applicable to scientific and engineering domains that demand accurate yet computationally tractable surrogate models of complex physical systems.

Speaker



Jichuan Tang

PhD candidate | University of Notre Dame

ID 275: Ensemble-based Uncertainty Quantification for Probabilistic Surrogate Models using SINDy

9:50 AM – 10:10 AM

Author(s): Soyeon Park, Seoul National University; Jaehwan Jeon, Seoul National University; Junho Song, Seoul National University

Surrogate modeling is increasingly essential in civil engineering because performance-based assessment, risk quantification, and structural reliability evaluation rely on repeated high-fidelity simulations, such as nonlinear time history analyses. Well-constructed surrogate models are required to enable efficient repeated evaluations and to provide transparent and interpretable representations that support uncertainty reasoning and risk-informed decision-making. Furthermore, because real-world structures are subject to diverse sources of uncertainty – arising from inherent variability, imperfect models, and uncertain parameters – surrogate models must be capable of rigorously quantifying these uncertainties. In this context, the Bayesian Sparse Identification of Nonlinear Dynamics (SINDy) framework offers a compact surrogate representation for efficient repeated evaluation, while identifying physics-interpretable evolution equations that provide insight into governing dynamics by rigorously accounting for both data noise and modeling sensitivities. However, even with these capabilities, the model-form uncertainty in SINDy can limit its ability to fully characterize aleatoric and epistemic uncertainties. To overcome the challenge, this study proposes a rigorous “ensemble-based” uncertainty quantification (UQ) framework grounded in probabilistic sparse identification to enable uncertainty-aware response prediction with explicit and interpretable evolution equations. Comparing multiple SINDy models, we distinguish between two key uncertainty types: an ensemble-based aleatoric uncertainty, which represents an upper bound on aleatoric uncertainty such as measurement noise, material variability, and fabrication tolerances; and an ensemble-based epistemic uncertainty, which reflects reducible uncertainty stemming from limited data and imperfect modeling assumptions. This distinction is critical because aleatoric uncertainty must be propagated in reliability analysis, whereas epistemic uncertainty can be reduced through additional data, improved identification, or refined modeling strategies. Specifically, the proposed framework is implemented as follows: first, an ensemble of SINDy models is constructed by varying candidate function libraries, sparsity thresholds, and training data realizations through resampling. An uncertainty decomposition grounded in the law of total variance is then employed to separate predictive uncertainty into aleatoric and epistemic components for each specific model, which is subsequently extended to an ensemble-level formulation to attribute uncertainty to both data scarcity and modeling choices. The resulting probabilistic evolution equations are embedded in standard dynamic response simulation schemes, enabling efficient prediction of response distributions and uncertainty bounds for unseen excitations at a fraction of the cost of full nonlinear analyses. The framework is demonstrated on a representative nonlinear single-degree-of-freedom system exhibiting hysteretic behavior under recorded and simulated earthquake excitations. Results show that the identified sparse models can recover dominant nonlinear mechanisms, reproduce key seismic demand statistics, and provide interpretable attribution of uncertainty sources. This supports a practical, transparent, and computationally efficient surrogate modeling approach for reliability-focused civil engineering applications.

Speaker



Soyeon Park

Graduate student | Seoul National University

ID 277: Uncertainty Quantification in Unified Hysteresis Modeling Using a Partially Bayesian Neural Architecture

10:10 AM – 10:30 AM

Author(s): Jongha Joo, Dept. of Civil, Urban and Environmental Engineering, Seoul National University; Jaehwan Jeon, Dept. of Civil, Urban and Environmental Engineering, Seoul National University; Junho Song, Dept. of Civil, Urban and Environmental Engineering, Seoul National University

Identifying structural hysteresis, the nonlinear path-dependent relationship between displacement and corresponding restoring force, with high accuracy is essential for structural design, post-disaster assessment, and decision making such as optimizing structural parameters and retrofit strategies. However, structures exhibit various hysteretic behaviors depending on seismic loading and material properties. To address this issue, we recently developed a unified physics-informed Transformer-based deep learning model to predict a wide range of hysteretic behaviors within a single architecture. Specifically, to overcome the challenge of limited data for specific materials, the model was developed by embedding features into the architecture and assigning individual projection heads for each target structural hysteresis while sharing the encoder to learn a common representation, thereby further leveraging different types of hysteresis data for training. However, deterministic point-wise predictions fail to provide measures of prediction credibility regarding data scarcity and cannot account for the inherent variability caused by experimental noise. Therefore, in this study, we apply Bayesian neural networks specifically in the projection head while maintaining a deterministic shared-encoder block to quantify the uncertainty induced by various factors. By doing so, the model can decompose epistemic uncertainty in the projection head and aleatoric uncertainty in the output, and leverage this information for decision making, such as adapting the training strategy or determining whether to rely on the predicted output. To evaluate the proposed framework, multiple hysteresis models including bilinear, m-IMK, Bouc-Wen class, and Ramberg-Osgood are used to generate datasets representing diverse hysteretic behaviors under varying model parameters and material properties. This study demonstrates that the proposed Bayesian model effectively quantifies uncertainties arising from data noise and the prediction credibility of the projection head, thereby enabling confidence-aware predictions of structural hysteresis.

Speaker



Jongha Joo

Graduate Student | Seoul National University

ID 359: Accelerating Atomistic–Continuum Simulations of Rippling Deformations in Multilayer Graphene via Functional Principal Component Analysis

10:30 AM – 10:50 AM

Author(s): Jonathan Oleson, Michigan Technological University; Abhishek Keripale, Michigan Technological University; Shashank Pathrudkar, Michigan Technological University; Susanta Ghosh, Michigan Technological University

We present a machine learning framework that accelerates atomistic–continuum simulations of rippling deformations in two-dimensional crystalline membranes containing millions of atoms. Suspended multi-layer 2D materials under mechanical loading exhibit highly nonlinear behavior, including complex rippling deformation patterns. Simulating the deformation of these systems through numerical approaches like atomistic-continuum-based methods is computationally expensive. We propose a machine learning (ML) model trained using atomistic–continuum simulation data for systems varying in strain and number of layers with the goal of predicting for unknown cases not seen in training. We view these systems as a collection of two-dimensional manifolds. A major challenge is that, due to the limited size of the simulation dataset, standard ML models struggle with predicting the high-dimensional deformations. To overcome this, we perform dimensionality reduction using functional principal component analysis (fPCA), to achieve a reduction from millions of degrees of freedom to under one hundred. By learning in the space of the fPCA coefficients, we can predict new coefficients for unknown systems and loadings and reconstruct the deformed configurations. Unlike multi-walled carbon nanotubes [1], the rippling deformation of suspended multilayer two-dimensional materials is highly sensitive to the initial random perturbations applied in simulations and varies strongly with the number of layers. As a result, the machine learning model cannot serve as an accurate surrogate due to the highly complex and chaotic nature of the rippling deformation, often producing patterns that resemble simulation data but remain far from the equilibrium solution. Instead, the proposed ML model is used to generate initial guesses for the atomistic–continuum solver, which are subsequently minimized, yielding substantial speed-ups while achieving comparable final system energies. We report results for multilayer graphene under uniaxial and biaxial compressions, with training data for the ML model generated by an in-house atomistic-continuum code using the foliation model [2]. We report the final energy as a metric for accuracy as well as the speed-up from minimizing the ML guesses versus running the foliation code.

[1] Upendra Yadav, Shashank Pathrudkar, and Susanta Ghosh. Interpretable machine learning model for the deformation of multiwalled carbon nanotubes. *Physical Review B* 103 (3), 035407, 2021. DOI: <https://doi.org/10.1103/PhysRevB.103.035407>

(<https://link.aps.org/doi/10.1103/PhysRevB.103.035407>)

[2] Susanta Ghosh, Marino Arroyo, An atomistic-based foliation model for multilayer graphene materials and nanotubes, *Journal of the Mechanics and Physics of Solids*,

Volume 61, Issue 1, 2013, Pages 235-253, ISSN 0022-5096,

<https://doi.org/10.1016/j.jmps.2012.07.002>.

(<https://www.sciencedirect.com/science/article/pii/S0022509612001366>)

Speaker



Susanta Ghosh

Assistant Professor | Michigan Technological University

ID 416: A Physics-Constrained Machine Learning Framework for Constitutive Modeling of Quasi-brittle Materials

10:50 AM – 11:10 AM

Author(s): Houlin Xu, Johns Hopkins University; Chenyang Li, Johns Hopkins University; Michael Shields, Johns Hopkins University; K.T. Ramesh, Johns Hopkins University

Quasi-brittle materials which undergo damage, such as concrete and rock, have been extensively studied. Numerous constitutive models have been proposed to describe the initiation and evolution of damage under complex loading conditions. A large fraction of the existing damage models are phenomenological in nature, relying heavily on empirical formulations and a large number of material parameters that must be calibrated through extensive experimental testing. Such models are computationally efficient, but the parameterization process is often time-consuming and costly. Further, such models often exhibit limited generalization when applied to loading paths or material conditions beyond those used for parameter calibration. Moreover, the uncertainty associated with damage evolution is typically not rigorously quantified, and the interpretability of data-driven adjustments to constitutive relations remains limited.

In this work, we propose a novel physics-constrained machine learning framework for damage-based constitutive modeling of quasi-brittle materials. The key idea is to embed mechanism-based physical constraints into the training process of machine learning models, thereby enforcing consistency with fundamental mechanical principles governing damage evolution. The proposed data-driven approach integrates physics-informed constraints derived from continuum mechanics and damage theory, such as admissible stress–strain relationships, energy dissipation requirements, and monotonicity of damage evolution. These constraints guide the learning process, reduce the feasible solution space, and improve the robustness and generalizability of the learned constitutive relations. The proposed framework also enables physically consistent uncertainty quantification in damage evolution, which is essential for reliability analysis of quasi-brittle materials under dynamic loading.

We demonstrate the proposed methodology by comparing it with the widely used Karagozian & Case (KCC) concrete model. The KCC model is extensively applied in predicting the dynamic response and damage evolution of concrete structures. Through this case study, we illustrate how physics-constrained machine learning can augment traditional constitutive modeling, providing a promising pathway toward reliable, interpretable, and data-efficient damage models for quasi-brittle materials.

Speaker



Houlin Xu

Dr. | Johns Hopkins University

ID 473: Accelerating Multiscale Simulations via Physics-Constrained Surrogate Modeling of Lower-Scale Physics

11:10 AM – 11:30 AM

Author(s): Cornelius Otchere, Johns Hopkins University; Kenneth Leiter, U.S. Army Research Laboratory; Jaroslaw Knap, U.S. Army Research Laboratory; Michael Shields, Johns Hopkins University

Multiscale modeling frameworks are often hindered by extreme computational costs which limit their usage in large scale engineering applications. While data-driven surrogate models have been employed to mitigate these costs, these surrogates often require a large amount of training data to maintain accuracy. In this work, we employ physics-constrained Gaussian Processes to replace expensive lower scale model evaluations within the Stochastic Hierarchical Multiscale Modeling framework. By embedding known governing equations/algorithms, we investigate whether we can achieve a more robust fit with reduced data requirements. We evaluate various formulations of these physical constraints and analyze their impact on predictive accuracy. The efficacy of the proposed approach is demonstrated on a quasistatic cantilever beam problem and a dynamic Taylor impact simulation.

MS 097: From Noisy Construction to Stable Structures in Soft and Granular Media

9:30 AM – 11:30 AM | Location: HUMN 150

Chair(s): Atanu Chatterjee; Florence Müller; Qinglin Wu; Saad Bhamla

Moderators



Florence Muller

Caltech

ID 877: Bees as Builders and Building Blocks of Biological Materials

9:30 AM – 10:10 AM

Author(s): Orit Peleg, University of Colorado Boulder

Blueprint-free construction in nature is noisy by default, yet it routinely yields structures that are load-bearing, adaptive, and repairable. Honeybees offer two striking case studies: they build materials (wax comb), and they become the material (swarm clusters). In this talk, I will connect these two processes through a soft and granular matter lens, asking how local rules and stochasticity can be leveraged to produce stable macroscopic form. First, I will treat swarm clusters as living, bonded aggregates that continuously remodel under gravity and environmental forcing. Using perturbation experiments, 3D imaging, and continuum force-balance, we find that the internal load distribution follows a robust strength to mass scaling, consistent with a design that avoids overstressing any layer while retaining the ability to flow and adapt. We also quantify how alignment and packing vary across the swarm, revealing a nematic-like organization that couples mechanics to thermoregulatory function. Second, I will describe collective honeycomb construction under geometrical frustration. By presenting colonies with 3D-printed, wax-coated “starter” frames that impose controlled lattice mismatches, we can map how defects nucleate, interact, and heal at interfaces. A minimal crystallography-inspired model based on short-range attraction and repulsion captures key defect statistics and suggests an “annealing” role for noise in achieving ordered cellular solids. Together, these results motivate testable phenomenological principles for distributed material design, with implications for noise-aware autonomous construction, soft robotics, and additive manufacturing in heterogeneous media.

Speaker



Orit Peleg

Associate Professor | University of Colorado Boulder

ID 927: Filamentous cyanobacteria as topological active matter – reconfigurable by light

10:10 AM – 10:30 AM

Author(s): Keita Richardson, University of Colorado Boulder; Ivan Smalyukh, University of Colorado Boulder

For the past 3.5 billion years, cyanobacteria have been one of the most fundamentally significant groups of organisms on the planet. The original photosynthesizers, they are responsible for the oxygenation of the earth's atmosphere, are the ancestors of photosynthetic systems in plants, and today continue to be highly abundant and modulate global climate. Moreover, certain cyanobacteria show the first signs of multicellularity, where individual cells connect into long one-dimensional chains. Here, we describe, and dictate, the formation of these filamentous cyanobacteria into higher order active matter structures.

We characterize in naturally occurring systems the three-dimensional geometry of tangled filaments, and analyse the non-trivial topology of these tangles, which are of biological relevance. Additionally, we explore strains with intrinsically chiral motility, and how this, alongside stochastic direction switching behaviour, drives emergent ensemble dynamics and structure not seen in achiral counterparts, providing insight into chiral active matter physics.

Moreover, we demonstrate spatiotemporal control over the formation of these higher order structures - using light. Strains that display phototaxis (directed movement of filaments toward light) can be patterned into novel structures such as the active nematic, where unique properties including self-propelling topological defects are seen. Using laser light allows for particularly precise control in space and time, which combines with the inherent stochasticity and in certain cases chirality of filament motility to produce a diversity of yet more different forms of active matter with unique structure and topology dependent upon the seeding conditions.

The characterization and control of filamentous cyanobacteria structure and dynamics not only allow for exploration of unique topological active matter physics but have the potential to in turn inform unique applications. Understanding the topology of knotted filaments in three dimensions has implications for the formation of biofilms, whilst increasingly sophisticated spatiotemporal control via light has implications for the growing industrial use of cyanobacteria in bioreactors. More exotic applications might include the creation of optically reconfigurable photosynthetic metamaterials, further harnessing the unique active matter physics our systems demonstrate.

Speaker



Keita Richardson

Graduate Research Assistant | University of Colorado Boulder

ID 1033: Waiting to Branch

10:30 AM – 10:50 AM

Author(s): Qinglin Wu, Georgia Tech/CU Boulder; Yufei Xiao, Georgia Tech/CU Boulder; Paul Bardunias, Florida Atlantic University; Atanu Chatterjee, Georgia Tech/CU Boulder; Saad Bhamla, Georgia Tech/CU Boulder

Subterranean termite (*Coptotermes gestroi*) colonies have extensive underground nest networks, which termites use to forage, build shelters, and transport resources and information. The tunnelling behavior has been widely studied; however, the physics of tunnelling - how individuals distribute workload and locally interact, govern the tunnel morphology and branching - is still poorly understood. In this study, we combine experimental and theoretical approaches to investigate the tunnelling behavior of *C. gestroi*. In experiments, we observed that most of the time, a jam forms at the tunnel tip, and the termite at the tip excavates and removes the particle while other termites wait in a queue. Previous research has shown that once a termite waits longer than the threshold, it becomes "impatient", which often leads to branching. Based on experimental observations and termite excavation behavior, we present a stochastic model to describe tunnel growth. We simulate termites as rigid disks with an excavation time, arrival rate, and characteristic waiting time. Our simulations show that the interplay among these three control knobs is sufficient to produce the various tunnel morphologies observed in experiments. Therefore, studying tunnelling behaviour in termite collectives allows us to design and develop algorithms for high-efficiency excavational robotic swarms.

Speaker



Qinglin Wu

Georgia Tech/CU Boulder

ID 28: Flow and fabricate: morphogenesis of termite shelter-tube networks

10:50 AM – 11:10 AM

Author(s): Atanu Chatterjee, Georgia Institute of Technology and University of Colorado Boulder; Kukhyun Lim, Fort Lauderdale Research and Education Center, University of Florida; Nan-Yao Su, Fort Lauderdale Research and Education Center, University of Florida; Saad Bhamla, Georgia Institute of Technology and University of Colorado Boulder

Subterranean termites must forage above ground while remaining hidden from predators and avoiding moisture loss. They meet this challenge by constructing intricate shelter-tube networks, collecting, shaping, and cementing soil grains even as thousands of nest-mates and food items stream through the same narrow passages. Despite their ecological importance, the collective rules that generate these structures remain poorly understood. Envisioning termite collectives as living granular matter that can both flow and fabricate, we present experiments and a minimal theoretical model to uncover the decentralized decision-making that drives shelter-tube morphogenesis. Together, these results reveal how simple stochastic rules, coupled with material feedback, give rise to reliable construction in a fluctuating environment. Beyond illuminating termite biology, our framework identifies engineering principles for designing autonomous robotic swarms capable of fabricating stable, self-supporting structures in granular or soft substrates.

Speaker



Atanu Chatterjee

Postdoctoral Associate | Georgia Institute of Technology and University of Colorado Boulder

MS 021: Scientific Machine Learning for Computational Geosciences

9:30 AM – 11:30 AM | Location: HUMN 1B90

Chair(s): Arash Fathi; Kami Mohammadi; Felix Herrmann; Somdatta Goswami; Kun Wang; Marcelo Dall'Aqua; Dakshina Valiveti

Moderators



Dakshina Valiveti

Manager, Computational & Data Sciences | ExxonMobil Technology and Engineering Company

ID 441: Discrete and Continuous Subsurface Property Retrieval from Sparse Radar Observations using Physics-Informed Neural Networks

9:30 AM – 9:50 AM

Author(s): Ishfaq Aziz, University of Illinois Urbana-Champaign; Mohamad Alipour, University of Illinois Urbana-Champaign

In various applications, ranging from environmental surveys to non-destructive sensing of infrastructure, radar sensing can be used to estimate dielectric properties (e.g., permittivity) of subsurface materials, such as concrete, soil, biomass, and asphalt. Subsurface material property can be discrete, layered, or continuously (gradually) varying. We present a physics-informed neural network (PINN)-based framework that can estimate both discrete and continuous permittivity of materials from sparse radar measurements. Unlike conventional data-driven approaches, the proposed PINN explicitly enforces electromagnetic wave physics through Maxwell's equations while fitting a limited number of measured waveforms, enabling accurate inversion with minimal training data. To measure waveform data at various locations across space, a custom radar was built integrating a vector network analyzer (VNA) and multiple radiofrequency (RF) antennas. The developed custom radar system is an order of magnitude cheaper than commercial ground-penetrating radars (GPRs).

We validated the framework with both simulations and experiments on multi-layered materials. Waveforms recorded by the array of spatially distributed RF antennas are used to train the PINN model and predict permittivity over space. The permittivity predicted by the proposed method agrees well with the permittivity measured with an independent in-situ sensor for both discrete ($R^2 \approx 0.93$) and continuous cases. The proposed PINN model can accurately reconstruct a smoothly varying permittivity profile and even capture subtle variations in permittivity ($\Delta \epsilon \approx 2$). Parametric analyses further demonstrate that reliable permittivity recovery is achievable using as few as three strategically placed sensors in two-layer systems. This approach is applicable to scenarios with both known and unknown material layering and boundaries. It outperforms the existing model-updating approach in terms of both accuracy and computational cost, especially in cases involving unknown material boundaries and limited observed data. Overall, this framework enables advanced electromagnetic characterization using sparse, low-cost radar systems.

Speaker



Ishfaq Aziz

Ph.D. Candidate | University of Illinois Urbana-Champaign

ID 456: Fisher-Informed Training Enables Physically Consistent Neural Operator-Based Inversion

9:50 AM – 10:10 AM

Author(s): Jeongjin Park, Georgia Institute of Technology; Grant Bruer, Georgia Institute of Technology; Huseyin Tuna Erdinc, Georgia Institute of Technology; Richard Rex Arockiasamy, Terra AI; Nisha Chandramoorthy, University of Chicago; Felix Herrmann, Georgia Institute of Technology

Many engineering and scientific applications in medical imaging, seismology, and subsurface fluid flow require repeated evaluations of forward models governed by computationally expensive partial differential equations (PDEs). To alleviate this cost, neural operator (NO) surrogates—such as Fourier Neural Operators (FNOs) and DeepONets—have recently emerged as efficient approximations of the underlying forward mappings. While existing work has largely focused on minimizing forward prediction error, inverse problems formulated as optimization tasks critically depend on the accuracy of local derivative information with respect to the current model iterate. However, standard NO surrogates trained solely to minimize forward data misfit can yield inaccurate or spurious gradients, including misleading sensitivities along directions that are unobservable under the true physics. When used in gradient-based inversion, these errors lead to model-iterate out-of-distribution (OOD) drift, pushing parameters into unphysical regimes and severely degrading inversion quality.

This work addresses a fundamental gap between surrogate accuracy for forward prediction and its reliability for inversion. We propose Fisher-Informed Neural Operators (FINO), a training framework explicitly designed for surrogate-assisted inversion. In addition to matching forward outputs, FINO learns the action of the Jacobian in the likelihood geometry, guiding the surrogate to capture parameter sensitivities along the most informative directions identified by the Fisher Information Matrix. This design ensures that surrogate-driven optimization updates respect the geometry of the underlying inverse problem by improving gradient accuracy in the subspace where model updates occur. At the same time, it reduces spurious derivative components that destabilize optimization.

We evaluate FINO on a diverse set of benchmark PDEs that pose distinct optimization challenges, including Darcy flow and incompressible laminar Navier–Stokes equations, which are representative of porous media flow and energy-related applications. We further demonstrate the method on a realistic high-dimensional inverse problem in seismic imaging, highlighting its relevance to large-scale, real-world inverse problems. Across all cases, we assess not only forward accuracy but also the physical correctness of inversion, including recovered parameter fields, optimization trajectories, and gradient fidelity.

Our results demonstrate that FINO produces inversion solutions that closely match those obtained with the true differentiable PDE solver in least-squares inversion. While Fisher-informed training incurs additional upfront cost during training, this investment is amortized across multiple inverse problem solves, leading to substantial computational savings once the surrogate is reused beyond a modest break-even point. At the same time, FINO significantly outperforms standard NO surrogates in terms of physical accuracy. We quantify these improvements using reconstruction error in the Sobolev norm, cosine similarity of gradients, and spectral analyses of inversion results. Complementing the empirical results, we provide a theoretical characterization showing how Fisher-informed training improves the accuracy of derivative information in the directions where model updates occur, while reducing gradient errors that are physically unobservable, thereby mitigating model-iterate out-of-distribution drift during optimization.

Speaker



Jeongjin Park

Graduate Research Assistant | Georgia Institute of Technology

ID 457: Well Control Optimization using Neural Operator Based Surrogate Models

10:10 AM – 10:30 AM

Author(s): Rodolfo Freitas, COPPE/Federal University of Rio de Janeiro; Gabriel Barros, COPPE/Federal University of Rio de Janeiro; Amanda Oliveira, COPPE/Federal University of Rio de Janeiro; Rômulo Silva, COPPE/Federal University of Rio de Janeiro; Ezequiel Santos, COPPE/Federal University of Rio de Janeiro; Dakshina Valiveti, ExxonMobil Technology and Engineering Company; Xiao-Hui Wu, ExxonMobil Technology and Engineering Company; Fernando Rochinha, COPPE/Federal University of Rio de Janeiro; Alvaro Coutinho, COPPE/Federal University of Rio de Janeiro

Optimizing well controls is a cornerstone of modern reservoir management, aimed at maximizing cumulative hydrocarbon recovery and net present value. Despite its importance, standard optimization workflows that rely on high-fidelity numerical simulators are often computationally prohibitive. These traditional methods require thousands of forward-function evaluations to navigate the complex objective functions of heterogeneous reservoirs, rendering real-time or robust optimization under uncertainty nearly impossible [1]. To overcome these computational bottlenecks, this work proposes a robust optimization framework powered by a novel class of hybrid neural operator surrogate models [2]. Unlike traditional surrogate models that are limited to specific grids or fixed input dimensions, neural operators learn the underlying mapping between infinite-dimensional function spaces. We specifically employ a hybrid Deep Operator Network (DeepONet) architecture designed to capture the multiscale nature of reservoir physics. This model incorporates a Fourier Neural Operator (FNO) as the branch network, leveraging its ability to learn global spatial correlations via the frequency domain, and a Multilayer Perceptron (MLP) as the trunk network. This hybrid approach effectively decouples and learns the intricate spatial and temporal features inherent in multiphase flow [2]. The framework is applied to the SPE10 Model 2 benchmark, a notoriously challenging test case characterized by high-dimensional input spaces and extreme geological heterogeneity. We address the complexities of robust optimization by incorporating stochastic geological realizations, varying both permeability and porosity maps, and dynamic operational parameters, specifically time-varying bottom-hole pressures (BHPs). By training on the mapping from these diverse geological/operational inputs to the resulting pressure and saturation fields, the hybrid surrogate serves as a rapid, differentiable proxy for the reservoir simulator. Our results demonstrate that the proposed hybrid surrogate accurately captures the nonlinear multiphase flow physics required for optimization while reducing computational cost by several orders of magnitude relative to traditional solvers. Ultimately, this work highlights the potential of neural operators to facilitate real-time decision-making and robust well control optimization in complex real-world reservoir assets where traditional methods fail to scale.

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- [2] E. S. Santos et al. Hybrid DeepONet Surrogates for Multiphase Flow in Porous Media. *arXiv*, 2025, arXiv:2511.029

Speaker



Fernando Rochinha

Professor | universidade Federal do Rio de Janeiro

ID 534: Latent-space data assimilation for complex geological systems using generative diffusion models

10:30 AM – 10:50 AM

Author(s): Guido Di Federico, Stanford University; Wenchao Teng, Stanford University; Louis J. Durlofsky, Stanford University

In subsurface flow modeling, geological reservoirs are represented on discrete grids, with each grid block characterized by a set of properties, such as permeability and porosity. These geomodels are constructed based on available geological knowledge, field measurements, and measured data from drilled wells. In the history matching (or data assimilation) step, the goal is to calibrate these prior geomodels such that, when numerical flow simulation is performed, model predictions closely match field observations. In the context of oil production, these observations may correspond to well pressure or flow rate measurements. The reduced uncertainty associated with the history-matched (posterior) models enables improved reservoir forecasts and thus better operational decisions.

In practical applications, geological models can have $O(10^6)$ or more grid blocks. Directly calibrating the individual block properties (i.e., model-space data assimilation) can be time-consuming and may compromise the spatial correlations of the geological features. To address these issues, geological parameterization is used to represent geomodels in terms of a small number of independent latent variables. In particular, deep-learning models can be trained to learn a parametric representation of a set of prior geomodels, in the form of a nonlinear mapping between the latent space and geomodel space (and vice-versa). The latent variables can then be calibrated to observed data using a history matching algorithm. Operating in the latent space significantly reduces the number of variables to determine while also ensuring geological realism (in terms of consistency with prior geomodels) in the posterior models.

In this work, we present a deep-learning-based parameterization using a generative latent diffusion model. We consider large 3D geomodels with fluvial channel geology. The flow setup involves an immiscible, two-phase (oil-water) flow problem, with nine wells. Synthetic “true” geomodels are used to provide (noisy) observed data and to assess the performance of the method. We compare model-space and latent-space data assimilation using a variety of algorithms, including ensemble-based and Monte Carlo methods. To enable the large number of flow evaluations required, we develop a data-driven surrogate, trained on high-fidelity numerical simulation results, to predict well injection and production rates as a function of time. Retaining geological realism in the posterior geomodels is shown to be challenging for ensemble-based model-space methods (e.g., traditional ESM DA or EnKF) due to the non-Gaussian nature of the channelized geomodels. The diffusion model parameterization, by contrast, utilizes a low-dimensional, multi-Gaussian latent space. Posterior geomodels using latent-space history matching are shown to be geologically realistic and consistent with the synthetic true models. Significant uncertainty reduction in well rate forecasts and geological scenario parameters is also achieved. Differences in latent-space history matching results using ensemble and Monte Carlo methods are observed and assessed.

Speaker



Guido Di Federico

PhD Candidate | Stanford University

ID 1032: Learning Dual-Porosity Flow: Adaptive Physics-Informed Neural Networks for Coupled Pore Networks

10:50 AM – 11:10 AM

Author(s): Venkat Maduri, University of Houston; Kalyana Nakshatrala, University of Houston

Porous media span a remarkably diverse range of systems—including fractured carbonate reservoirs, ultra-tight shale formations, architected metallic foams, tissue-engineering scaffolds, and even plant xylem conduits. In many of these environments, flow and transport processes are governed by two hierarchically distinct but hydraulically coupled pore domains: a larger, highly permeable network that serves as the main conduit for flow, and a finer, more tortuous micro-pore network that controls storage, diffusion, and exchange dynamics. To accurately capture the resulting multiscale mass and solute transfer, the double-porosity/permeability (DPP) framework offers a powerful modeling approach. However, conventional grid-based solvers can become burdensome in workflows that demand rapid scenario screening, inverse parameter estimation, or continual updating from sparse measurements. In this work, we develop a physics-informed neural network (PINN) framework tailored for DPP flow. The approach employs a shared network representation for the coupled pore domains and uses residual balancing (adaptive constraint weighting) to prevent one governing equation or coupling term from dominating training. To improve efficiency and accuracy, we further introduce an error-guided collocation strategy that adaptively concentrates training points near sharp pressure gradients, permeability interfaces, and evolving flow fronts. Representative numerical studies demonstrate that the proposed mesh-free framework can accurately reproduce DPP dynamics while remaining stable under strong macro–micro permeability contrast and avoiding artifacts such as excess numerical diffusion and spurious oscillations that commonly arise in standard discretizations. Finally, we highlight how the network can be incrementally retrained as new laboratory, logging, or in-situ sensor data arrive, enabling continuously updated forecasting for applications including tight formations, subsurface storage (CO_2/H_2), and geothermal heat-exchange optimization

Speaker



Venkat Maduri

Graduate student | University of Houston

MS 040: Mechanics of Wood and Wood-Based Materials

9:30 AM – 11:30 AM | Location: CLUB 4-5

Chair(s): Markus Lukacevic; Eric Landis; Fiona O'Donnell; Luis Zelaya-Lainez; Josef Füssl

Moderators



Markus Lukacevic

Dr. | TU Wien (Vienna University of Technology)

ID 55: Experimental Stability Analysis of Glued Laminated Timber Pillars

9:30 AM – 9:50 AM

Author(s): Reyolando Brasil, University of Sao Paulo; Geise Aparecida Pereira, University of Sao Paulo

We present the results of a laboratory research on the instability loads of GLT columns compared to the values recommended by the Brazilian Standard for Design of Wooden Structures, Finite Elements models and theoretical buckling loads.

A Brazilian wood was chosen, The nondimensional slenderness of the specimens was varied from 20 to 200, in increments of 20, and 6 specimens of each slenderness were made.

Axial compression tests were carried out on the samples as simply supported at both ends, instrumented for lateral displacement at mid-span and for instability load. For each slenderness, mean and standard deviation of these loads were calculated.

Next, a comparison was made of the stress-slenderness curve obtained in the tests with the curves given by the Brazilian Standard for the Design of Wooden Structures, ABNT NBR 7190:1997 and ABNT NBR 7190:2022 versions, conceptually very different.

We also checked results with a simple Finite Elements numerical model and theoretical values in literature that are very close to values given by Brazilian Standard ABNT NBR 7190:2022

Speaker



Reyolando Brasil

Professor | University of São Paulo

ID 176: Development of Inorganic-Bonded Bamboo Composite for Structural Applications

9:50 AM – 10:10 AM

Author(s): Ernian Zhao, Shandong Jianzhu University; Qiaoling Liu, Shandong Jianzhu University; Hanshu Zhang, Coastal Carolina University; Shurong Li, Shandong Jianzhu University; Qingxia Yue, Shandong Jianzhu University; Xin Zhang, Shandong Jianzhu University

Developing green bamboo-wood structures represents a significant approach to achieving environmental sustainability. Although bamboo is a renewable natural biomass material, its application in modern engineering structures is constrained by limitations in geometric size and mechanical performance. In response, this study introduces a new bamboo-based composite material, inorganic-bonded bamboo composite (InorgBam) [1, 2], fabricated using modified magnesium oxysulfide inorganic adhesive to bind bamboo bundles. The addition of silica fume, sodium silicate, and citric acid effectively improves the adhesive's wettability and interfacial compatibility. To obtain the mechanical properties and establish the constitutive model of the InorgBam, mechanical tests were conducted under multiple loading conditions [3]. Further, full-scale fire tests on InorgBam beam and columns under ISO 834 heating conditions were conducted to evaluate their resilience under fire [4]. The deflections of midspan of beam specimens and charring depths of column specimens under various duration of fire tests were obtained, respectively. These tests indicate that InorgBam exhibits favorable mechanical properties, fire resistance, and long-term properties, demonstrating promising potential for application in green building structures.

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Speaker



Zhang Hanshu

Assistant Professor | Coastal Carolina University

ID 398: Numerical Simulation of Timber-Concrete Composite (TCC) Push-out Test By Developing a New Boundary Condition with Cohesive Interaction

10:10 AM – 10:30 AM

Author(s): Lok Hei Lee, The Hong Kong University of Science and Technology; Yuxin Pan, The Hong Kong University of Science and Technology

Timber-concrete composite (TCC), which combines the structural advantages of concrete and mass timber, is a sustainable construction material for beam and floor system. The structural performance of TCC beam is governed by the connection system along the composite interface, and among different connections, notch connection shows optimal structural performance and economic efficiency. Understanding and prediction of notch performance in TCC beams heavily rely on insight obtained from push-out test, and certain parameters could only be obtained through numerical simulation. Currently proposed simulations for push-out test either show over-estimation of slip modulus or inaccurate prediction of loading capacity of notch and failure mode. To address these challenges, this study proposes a systematic push-out test simulation approach for different notch designs in linear elastic stage. A novel boundary condition is developed to simulate the roller support that restrain concrete rotation due to eccentricity of shear loading. By introducing pressure loading on concrete and establishing a relationship of shear loading and normal constraint through moment equilibrium, an accurate load-slip relationship is simulated. The commercial numerical software, ABAQUS, was used to simulate timber cracking with cohesive interaction. The model was verified with experimental results of specimens with different notch designs, i.e. notch depth and timber length, and the simulation results match well with the experimental failure mode, loading capacity. The proposed simulation approach provides an accurate way to simulate the roller constrain condition. These findings are expected to increase the accuracy of future simulations of non-linear push-out test.

Speaker



Xuanyi Lu

PhD Candidate | The Hong Kong University of Science and Technology

ID 459: Macroscopic Elastic Characterization and UV Stability of Polymer-Infused Transparent Wood

10:30 AM – 10:50 AM

Author(s): Luis Zelaya-Lainez, TU WIEN; Markus Lukacevic, TU WIEN; Sarah Näher, TU WIEN; Johanna Schindler, TU WIEN; Olaf Lahayne, TU WIEN; Markus Königsberger, TU WIEN; Daniele Nuvoli, University of Sassari; Alberto Mariani, University of Sassari; Josef Füssl, TU WIEN

Transparent wood (TW) is produced by delignifying wood and infiltrating it with a polymer. TW exhibits enhanced and direction-dependent elastic properties. The understanding of the elastic properties is crucial for its use in structural and functional applications. To obtain the macroscopic mechanical behavior of TW we used a combination of non-destructive (ultrasonic tests) and quasistatic methods (tensile and bending tests). The aforementioned enable the determination of orthotropic stiffness components along radial, tangential, and longitudinal directions. The results of the experimental campaign show that the polymer infiltration significantly increases stiffness and homogenizes the mechanical response compared to native wood. The biggest improvements are observed in the tangential plane. Ultrasonic testing also allows us to monitor the environmental durability of TW. Our ultrasonic tests reveal that prolonged UV-A exposure causes only minor fluctuations in stiffness and negligible optical degradation in TW. This indicates that TW has an effective shielding against UV radiation by mixing a delignified wood scaffold with some of the studied polymers. All the mentioned experiments establish that TW is a mechanically stable, UV-resistant, and sustainable composite material for many applications, such as in the construction sector, the automotive industry, architectural structures, etc.

Acknowledgements: The Al-TranspWood project, HORIZON-CL4-2023-RESILIENCE- 01-23 (Grant Agreement 101138191), is gratefully acknowledged. This project is co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them. Additionally, the financial support by the Austrian Federal Ministry of Economy, Energy and Tourism, the National Foundation for Research, Technology and Development, and the Christian Doppler Research Association is also gratefully acknowledged. Further, the authors acknowledge the company partner HS Timber Group GmbH for the financial support.

Speaker



Luis Zelaya-Lainez
TU WIEN

ID 523: Deep Learning-Enhanced Continuum Micromechanics Framework for Nonlinear Homogenization of Wood-Based Biocomposites with Complex Inclusion Morphologies

10:50 AM – 11:10 AM

Author(s): Markus Lukacevic, Christian Doppler Laboratory for Next-Generation Wood-Based Biocomposite, Institute for Mechanics of Materials and Structures, TU Wien; Michael Schwaighofer, Institute for Mechanics of Materials and Structures, TU Wien; Markus Königsberger, Institute for Mechanics of Materials and Structures, TU Wien; Dominik Kratzer, Christian Doppler Laboratory for Next-Generation Wood-Based Biocomposite, Institute for Mechanics of Materials and Structures, TU Wien; Josef Füssl, Christian Doppler Laboratory for Next-Generation Wood-Based Biocomposite, Institute for Mechanics of Materials and Structures, TU Wien

The transition toward sustainable construction necessitates the upcycling of sawmill by-products, such as wood chips and sawdust, into high-performance biocomposites. These residues are advantageous because they retain wood's native, high-strength microstructure while serving as a carbon sink [1,2]. However, the irregular geometries and heterogeneous nature of these constituents pose significant challenges for predicting macroscopic mechanical responses, particularly in nonlinear regimes [3].

The macroscopic response of such heterogeneous materials is dictated by the morphology and properties of their constituents. While classical mean-field homogenization schemes based on Eshelby-type solutions [4] are computationally efficient, they typically rely on idealized inclusion geometries and uniform strain assumptions that limit accuracy. This work proposes a hybrid framework integrating finite element-based Eshelby analysis with continuum micromechanics and machine learning to enable efficient nonlinear homogenization. The core innovation involves replacing single, average strain concentration tensors with discretized strain concentration fields extracted from FE simulations of non-ellipsoidal inclusions. By capturing these local heterogeneities, the framework enables the progressive plasticization of phases within continuum micromechanics.

Specifically, a neural network is trained to predict clustered concentration tensors as a function of inclusion geometry and phase stiffnesses [5]. This allows the macroscopic nonlinear behavior to be computed by treating each cluster as an individual phase, ensuring results agree with full-field simulations without the need for explicit microstructure generation. As a critical extension, the framework is expanded to model curved fibers, allowing for a more realistic representation of the complex morphology and connectivity inherent in reassembled sawmill residues. This simulation-guided strategy provides a robust foundation for the design of next-generation 3D biocomposites, facilitating the transition from low-value wood waste to high-performance structural elements.

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Speaker



Markus Lukacevic
Dr. | TU Wien (Vienna University of Technology)

ID 561: Dowel bearing performance of cross laminated timber

11:10 AM – 11:30 AM

Author(s): Fiona O'Donnell, Swarthmore College; Baiyu Chen, Northeastern University; Antonio Cristian, Universitatea Politehnica Timisoara; David Padilla-Llano, Simpson Gumpertz & Heger; Sujit Bhandari, Northeastern University; Jerome Hajjar, Northeastern University

The development of novel structural systems using engineered wood products requires experimental testing to characterize their performance and validate their reliability. Prior to physical testing, finite element modeling (FEM) is employed to assess the design viability and guide the experimental apparatus design. A common challenge in FEM of engineered wood products is developing accurate material models and defining mechanical properties. This research addresses this challenge in the context of cross laminated timber (CLT) connections, by developing a finite element model for dowel bearing behavior calibrated to experimental tests. This presentation will describe 1) an experimental program for characterizing clear wood material properties and CLT scale dowel bearing performance; 2) the development of a non-linear finite element model for dowel bearing load-displacement response; and 3) probabilistic results for dowel bearing response of CLT.

An experimental program was performed at both the clear wood scale and CLT scale to define material properties and structural behavior. Clear wood specific gravity and compression parallel and perpendicular to grain were measured in accordance with ASTM D143. Dowel bearing performance was measured following ASTM D5764 for several orientations and dowel diameters. Tests were performed on five-ply and seven-ply spruce-pine-fir (SPF) CLT, with dowel diameter ranging from 0.75 to 1.75 inches. Experimental results were compared to predicted performance in accordance with the National Design Specification for Wood Construction.

A nonlinear finite element model was developed to model the dowel bearing performance for the various CLT orientations and dowel diameters. The steel dowel was modeled using an isotropic stress-strain relationship developed through experimental testing, while the lumber was represented by a continuum damage model calibrated to the measured clear wood properties. Variability in dowel bearing response was quantified through probabilistic simulations based on the statistical distributions of experimentally measured material properties. The model provides insight into the influence of material variability on CLT connection performance.

Speaker



Fiona O'donnell

Assistant Professor | Swarthmore College

MS 045: Materials Science and Mechanics of Earthen Construction

9:30 AM – 11:30 AM | Location: CASE E230

Chair(s): Samuel J. Armistead; Wil V. Sruhar III

Moderators



Samuel Armistead

Research Associate & Lecturer | University of Colorado, Boulder

ID 123: Amino Acid Stabilization of Bentonite and Kaolinite for Terrestrial and Extraterrestrial Construction

9:30 AM – 9:50 AM

Author(s): Yuhuan Wang, University of Colorado, Boulder; Samuel J Armistead, University of Colorado, Boulder; Wil V Sruhar, University of Colorado, Boulder

Bio-stabilized earthen materials provide a pathway toward sustainable, high performance extraterrestrial earthen construction by enhancing mechanical properties while reducing environmental impact and alleviating resource constraints. Inspired by the robust amino-acid clay interactions that are thought to have played a critical role in the origin-of-life, this study investigates whether such interactions can be harnessed to enable high-performance earthen construction materials on Earth and on Mars. Representative amino acids spanning positively charged (e.g., arginine, histidine), negatively charged (e.g., aspartic, glutamic), polar hydrophilic (e.g., asparagine, glutamine, serine, and threonine acids), and nonpolar hydrophobic (e.g., alanine, leucine, tryptophan, and glycine) classes are employed, with kaolinite and bentonite clays, to elucidate amino acid-clay interactions. A suite of physicochemical characterization techniques, including FTIR, TGA, XRD, particle size analysis, and zeta potential measurements, is employed to investigate how amino acid functional groups and surface charges influence binding efficiency with clays and to elucidate the underlying interaction mechanisms. Nanoindentation is employed, for the first time in bio-stabilized earth, to directly assess how such biomolecular binding translates into the mechanical performance of the resulting earthen materials. The results provide mechanistic insights into amino acid-clay interactions and how such binding interactions enhance the mechanical properties of the earthen materials. Collectively, these findings offer mechanistic insight into the development of sustainable, biologically inspired stabilization strategies for terrestrial and extraterrestrial earthen construction materials.

Speaker



Yuhuan Wang

postdoctoral associate | University of Colorado, Boulder

ID 140: Towards Building on Mars: Interactions Between Charged Polysaccharides and Martian Regolith

9:50 AM – 10:10 AM

Author(s): Danielle N. Beatty, University of Colorado, Boulder; Samuel J. Armistead, University of Colorado, Boulder; Simon C. Cox, University of Colorado, Boulder; Wil V. Srubar, University of Colorado, Boulder

Due primarily to the cost of transporting materials from Earth, in situ resource utilization is paramount to ensuring sustainable and practical construction on other planets, including Mars. Previous work showing high performance, biopolymer-stabilized earthen materials, and the potential for producing biopolymers with tunable properties at scale on the surface of Mars, indicate promise for the use of biopolymer-stabilization with Martian regolith. While promising, a full understanding of the mechanisms and materials science underpinnings of bio-stabilization of regolith has yet to be elucidated. This work explores the interactions and binding behaviors between Martian global simulant (MGS-1) (selected as a representative regolith analog) and its constituent minerals, with charged polysaccharides. Martian regolith (i.e., the loose top layer of rock material covering the surface of Mars) consists primarily of aluminosilicate minerals and mineral solid solutions, including anorthosite, basalt, bronzite, and olivine, among others. These minerals primarily exist with negative surface charges under normal conditions. These surface properties indicate potential for electrostatic binding, and thereby stabilization, through the addition of positively charged biopolymers. To understand binding affinity of MGS-1 and its constituent minerals with charged biopolymers, four polysaccharides with varying charge were selected for testing: cationic guar gum, anionic guar gum, and two uncharged forms of guar gum (native guar gum and hydroxypropyl guar gum). By selecting variations of the same polysaccharide structure, the effects of charge were isolated from any effects due to polysaccharide size, conformation, or chemistry. The binding of each charged guar gum derivative with MGS-1 and each of its constituent minerals was characterized using thermal gravimetric analysis, zeta potential analysis, Fourier transform infrared spectroscopy, and X-ray diffraction. The effects of polysaccharide addition and polysaccharide binding on regolith stabilization were characterized by testing the unconfined compressive strength of 10 mm x 20 mm compacted cylindrical samples. This research discusses critical mechanistic insights into polysaccharide-Martian regolith interactions and the impact of these interactions on mechanical properties. This study highlights the potential of using bio-stabilization to create high performance building materials using Martian regolith, thereby unlocking in situ resource utilization for sustainable and practical on-Mars construction.

Speaker



Danielle Beatty

Postdoctoral Research Associate | University of Colorado Boulder

ID 271: Establishing Structure-Property Relationships for Polysaccharide-Stabilized Earthen Construction Materials

10:10 AM – 10:30 AM

Author(s): Rebecca Mikofsky, University of Colorado Boulder; Samuel Armistead, University of Colorado Boulder; Danielle Beatty, University of Colorado Boulder; Wil V. Srubar III, University of Colorado Boulder

Earthen materials are a promising low-cost, sustainable construction alternative with high thermal efficiency, recyclability, low emissions, and local availability. Biopolymer additives improve the limited strength and durability of earthen materials which currently limit their widespread use. However, little is known about the complex biopolymer-earth interactions and their contributions to performance. Through a multiscale materials-science approach, this study investigated the micro-scale physicochemical interactions between three common earthen materials (kaolinite clay, bentonite clay, and sand) and five polysaccharide biopolymers: cationic hydroxypropyltrimonium guar (CGG), nonionic hydroxypropyl guar gum (HPGG), nonionic guar gum (GG), anionic carboxymethyl hydroxypropyl guar (AGG), and anionic sodium alginate (SA). These biopolymers were selected to highlight comparisons of the equivalent structures with different charges (i.e., CGG, GG, AGG) and comparisons of different structures or chemistries with equivalent charges (i.e., AGG vs SA and HPGG vs GG). At the microscale, chemical (thermogravimetric analysis, Fourier transform infrared spectroscopy, and zeta potential) and microstructural methods (particle size, X-ray diffraction, and scanning electron microscopy) were used to assess biopolymer-mineral binding interactions. At the macroscale, compacted engineered soil (2:1 sand:clay) samples with 1% biopolymer-addition were created at different water contents based on the optimum moisture content and liquid limits. Hardened-state strength and water durability were evaluated for these samples and biopolymer-stabilized sand samples. For all three minerals, the micro-scale results indicated the importance of charge as cationic, anionic, and nonionic guar gums (CGG, AGG, and GG) had distinct binding behaviors with anionic biopolymers having the weakest binding. This effect was especially prominent in bentonite where CGG had much stronger binding than GG and AGG due to the attraction between positive biopolymer groups and bentonite's negative layer charge. Contrasting between equivalently charged biopolymers (nonionic GG > HPGG and anionic AGG > SA) revealed that structure and functional group chemistry can meaningfully impact binding behavior. For the macro-scale performance, the effects of biopolymer structure and charge were evident in addition to macro-scale properties and processing parameters such as hardened-state density and initial water content. Similarly to the micro-scale, biopolymer charge had the highest sensitivity among the biopolymer properties. For example, in sand and higher water content kaolinite-sand, nonionic charge was linked to higher strength. While anionic biopolymers generally had lower strength and water durability overall, there were exceptions due to the differences in structure and chemistry such as SA's ability to increase strength at low water content in kaolinite-sand while AGG did not. For water durability, retained mass had a clear connection to binding. For instance, non-binding SA retained no mass in kaolinite-sand while in comparison binding nonionic and cationic guar reduced the mass loss versus the controls. Through connecting micro- and macro-scale conclusions, this study advances the understanding of multi-scale structure-property relationships, paving the way towards high-performance biopolymer-stabilized earthen materials.

Speaker



Rebecca Mikofsky

University of Colorado Boulder

ID 282: Recyclable Hydrogel-based Concrete Made with Yeast

10:30 AM – 10:50 AM

Author(s): Shing Chi Lam, The Hong Kong University of Science and Technology; Ning Liu, The Hong Kong University of Science and Technology; Wenwei Huang, The Hong Kong University of Science and Technology; Qikun Yi, The Hong Kong University of Science and Technology; Fei Sun, The Hong Kong University of Science and Technology; Jishen Qiu, The Hong Kong University of Science and Technology

The fabrication of conventional construction materials, such as Portland cement concrete, faces substantial impediments when confronted with distinctive environmental conditions characterized by resource scarcity or extreme operational parameters. These challenges necessitate the development of novel, sustainable material solutions for the establishment of resilient habitats and critical infrastructure. Prior investigations have successfully demonstrated a bio-inspired approach, utilizing a natural polymer, specifically gelatin, in conjunction with genetically engineered *Saccharomyces cerevisiae* (yeast) cells. This methodology facilitates the production of hydrogels capable of effectively binding granular aggregates, such as sand, to form concrete-like composites under laboratory-simulated extreme conditions. These Bio-hybrid hydrogel-based concrete (Bio-HBCs) are noteworthy for their exceptional regeneration capabilities, having been shown to retain their mechanical properties across five successive material generations, thereby offering considerable potential for reduced material waste.

Building upon this foundational work, the present study endeavors to systematically investigate the intrinsic correlation between the fresh rheological properties of Bio-HBCs and their ultimate hardened mechanical characteristics. A comprehensive understanding of this relationship is pivotal for establishing predictive models and robust quality control protocols, which are essential for optimizing material composition and processing.

Speaker



Shing Chi Lam

Mr. | Hong Kong University of Science and Technology

ID 349: High-throughput Methods for Optimizing the Mechanical Properties of Bio-stabilized Earthen Construction

10:50 AM – 11:10 AM

Author(s): Samuel J. Armistead, University of Colorado Boulder; Rebecca A. Mikofsky, University of Colorado Boulder; Wil V. Srubar III, University of Colorado Boulder

Bio-stabilization provides a critical route to sustainable, high-performance earthen materials by addressing the key limitations that restrict their widespread application, particularly low mechanical strength and durability. Improving these properties is essential to enable broader structural and engineering use of earthen construction. The effectiveness of bio-stabilization is governed by complex chemical interactions between biopolymers and earth mineral components, which directly influence the resulting mechanical behavior. Given the diversity of earthen minerals and the wide range of biopolymer building blocks, there is a clear need for high-throughput approaches capable of systematically exploring and optimizing the mechanical properties of bio-stabilized earthen materials.

This presentation outlines emerging high-throughput methods for the optimization of bio-stabilized earthen construction materials. The first approach focuses on solid-phase analysis through a mineral binding characterization (MBC) technique, employing X-ray diffraction, particle size analysis, attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR), and zeta potential measurements to characterize biopolymer–earth physicochemical interactions and microstructures. The potential of this approach to rapidly optimize the properties of compressed earth blocks, as well as emerging 3D-printed earthen architectural elements, is discussed.

The second approach targets solution-phase behavior through a rapid extraction and binding assessment technique (REBAT), using ATR-FTIR and UV analysis to rapidly assess biopolymers extracted from heterogeneous biomass waste, their interactions with earthen minerals, and the resulting mechanical properties of compressed earth blocks. This approach offers the potential for a 500-fold increase in assessment rate, while enabling identification of the fundamental biopolymer classes (i.e., polysaccharides, proteins, and lipids) and combinations thereof responsible for property enhancement.

Overall, this presentation highlights the potential of high-throughput approaches in accelerating the development of high-performance earthen materials. These methods further show promise in providing a foundation for emerging platforms such as synthetic biology, advanced processing, and additive manufacturing, supporting the widespread adoption of earthen construction in the 21st century on Earth and beyond.

Speaker



Samuel Armistead

Research Associate & Lecturer | University of Colorado, Boulder

ID 684: Development of Compressed Earth Blocks with High Green Strength for Rapid Masonry Construction

11:10 AM – 11:30 AM

Author(s): Nitin Kumar, Indian Institute of Technology Patna; Michele Barbato, University of California Davis

Masonry construction has been employed since prehistoric times, evolving from sun-dried earthen bricks to fired clay bricks and, more recently, concrete masonry units. Despite their widespread adoption, conventional masonry units require significant pre-use processing, such as drying, firing, or curing, which delays construction and increases costs associated with energy consumption, storage, and handling. These limitations motivate the development of alternative masonry units capable of achieving sufficient early-age strength for immediate use after fabrication. Compressed earth blocks (CEBs) offer a promising solution due to their low embodied energy and reliance on locally available materials. This study hypothesizes that by optimizing water content and applying sufficiently high molding pressure, CEBs can develop adequate early mechanical strength to support rapid masonry construction. Additionally, the incorporation of suitable binders is expected to enhance long-term strength, enabling masonry constructed with such blocks to satisfy structural performance requirements prescribed by design codes.

To examine this hypothesis, an experimental program was conducted in which CEBs were fabricated under molding pressures ranging from 5 MPa to 100 MPa. For each pressure level, the water content was varied from 0% up to the threshold at which water expulsion occurred, representing the maximum sustainable moisture content. The resulting blocks were evaluated for key physical and mechanical properties. The results indicate that increasing molding pressure significantly enhances both the physical integrity and mechanical performance of CEBs. For a given molding pressure, block properties improve with increasing water content up to an optimal value, beyond which additional moisture yields marginal benefits or, at lower pressures, a reduction in performance. Notably, CEBs produced at higher molding pressures exhibit substantial green compressive strength, allowing masonry construction to commence immediately after fabrication without curing delays. These findings demonstrate the potential of high-pressure CEBs as viable masonry units for rapid, cost-effective, and sustainable construction using locally sourced earth materials. Furthermore, the technology is compatible with automated masonry-laying systems, enabling block-based three-dimensional printing of masonry and opening new opportunities for efficient and eco-friendly construction in high-demand urban environments.

Speaker



Michele Barbato

Professor | University of California, Davis

MS 052: Stability of structures: Advances across time and scales

9:30 AM – 11:30 AM | Location: CASE E240

Chair(s): Noël Challamel; Hayder Rasheed; C.W. Lim; Stylianos Yiatros; Hyeyoung Koh

Moderators



Hayder Rasheed

Professor | Kansas State University

ID 639: Thermal effects on thin-walled roof deck panels under elevated diurnal temperatures

9:30 AM – 9:50 AM

Author(s): Malik Farooq, Washington State University; Hyeyoung Koh, Washington State University

Thin-walled steel structures are sensitive to thermal variations, which induce repeated expansion and contraction and influence both structural behavior and stability. Although extreme thermal environments such as heatwaves are becoming more frequent, current design practice does not explicitly consider thermal effects as structural loading. This study experimentally investigates profiled metal roof decks subjected to elevated diurnal temperatures to assess the influence of heat and repeated thermal variation on structural response.

A purlin-bearing rib panel with a 12-ft support-to-support span, restrained by fasteners at the supports, was instrumented with distributed fiber optic sensors to collect continuous strain and temperature profiles. Sensors were placed along the deck span and around fastener regions to examine thermal effects in both free and restrained zones. Multiple heating scenarios were considered, including full sun exposure, partial shading, and no sun, to examine nonuniform temperature and strain fields under different environmental conditions. The measured temperature and strain responses show localized, high magnitude variations along the deck, which indicate that thermal effects are significant and should not be neglected. Repeated thermal variations may be treated as cyclic thermal loading, and future work will use the experimental data to develop nonuniform temperature fields for numerical analysis of thin-walled steel members.

Speaker



Hyeyoung Koh

Assistant Professor | Washington State University

ID 404: Roll Buckling of Long-Span Girders - Experiments and Theory

9:50 AM – 10:10 AM

Author(s): William D. Galik, Idaho State University; Richard Wiebe, University of Washington; John Stanton, University of Washington; Daniel Gaxiola, University of Washington

Long-span precast concrete girders are susceptible to a form of instability during trucking and lifting commonly known as roll buckling, and herein as Lateral-Roll Buckling (LRB). This happens due to the interaction of weak-axis deformation and roll rotation at flexible supports (i.e., truck bed, or hanging from cables). Beyond a critical buckling state, the "preferred" upright configuration loses stability, with the girder instead finding a deformed, often highly-stressed, configuration. In a series of pioneering papers [1,2], Robert F. "Bob" Mast analytically investigated this phenomenon, and provided elegant expressions for the buckling conditions. Those expressions have since then served as the basis for lateral stability analysis in the design of girder transport protocols. However, driven by the benefits of accelerated bridge construction, precast girders are being fabricated with ever longer, and more slender, spans. There is a need to investigate whether twist may still be safely ignored with modern girder spans, and more generally, provide the analytical tools to incorporate twist to assess Lateral-Torsional-Roll Buckling (LTRB).

The presentation will provide a summary of an overall arc of research in this topic. It begins with early experimental work on LRB and the original equations by Bob Mast, then shows updates that incorporate twist, and a recent experimental program by the authors. The fundamental principles of LTRB are also described using a simplified deformable pendulum model, which allows for a qualitative description of the bifurcation diagram.

[1] Mast, R. F. "Lateral stability of long prestressed concrete beams-Part I." PCI Journal, 34(1), 1989, pp. 34-53.

[2] Mast, R. F. "Lateral Stability of Long Prestressed Concrete Beams-Part II." PCI Journal 38(1), 1993, pp. 70-88.

Speaker



Richard Wiebe

Associate Professor | Civil and Environmental Engineering

ID 295: Assessment of Temperature Induced Tilting in the Streicker Bridge

10:10 AM – 10:30 AM

Author(s): Yuxi Cao, Princeton University, Department of Civil and Environmental Engineering; Branko Glišić, Princeton University, Department of Civil and Environmental Engineering

Understanding of how structural behaviors respond to environmental changes over time is essential for ensuring the long-term integrity of in-service bridges. Structural Health Monitoring (SHM), which transforms real-world bridges into "living laboratories" by generating vast amounts of measurement data—such as displacement and temperature data amongst others—provides a valuable means to analyze structural behaviors and further assess structural performance. More specifically, by leveraging the displacement and temperature data obtained from SHM, a method can be developed to identify unusual structural behaviors such as potential lifting and tilting of bridge decks.

Streicker Bridge, a pedestrian bridge with complex geometry built on the Princeton University campus, has been instrumented with SHM. Strain and temperature sensors were embedded in the concrete deck of the bridge, while five displacement sensors were installed at the southeast abutment. Over time, an apparently unusual behavior of displacement sensors was noticed indicating potential partial lifting and tilt of the deck. Temperature variations were preliminarily identified as the cause of this behavior, but that assumption was not validated quantitatively.

Consequently, this study aims to explore a method for assessing potential lifting and tilting of the deck of the Streicker Bridge at the southeast abutment. The process involves revisiting archival sensor data to analyze and interpret the recorded displacement and temperature measurements and describe and quantify their mutual dependency. The method explores physics-informed and data-driven approaches to uncover the underlying mechanisms that are in the cause of potential lifting and tilt, and to identify how they evolve with temperature cycles.

Speaker



Yuxi Cao

PhD Student | Princeton University, Department of Civil and Environmental Engineering

ID 112: Drift Localization Control in Flexible Frames Using Stepping Rocking Walls

10:30 AM – 10:50 AM

Author(s): Mehrdad Aghagholizadeh, Loyola Marymount University

Near-fault ground motions characterized by long-period velocity pulses can induce severe interstory drift concentration and residual deformation in moment-resisting frames, particularly in mid- and high-rise buildings. These effects often trigger weak-story mechanisms and poor post-earthquake repairability, even when collapse is avoided. This study examines how stepping rocking shear walls, used as external retrofit elements, modify the nonlinear dynamic response of moment-resisting frames and suppress pulse-driven damage mechanisms.

Nonlinear response-history analyses are performed on benchmark 9-story and 20-story SAC steel moment-resisting frames, evaluated in their original configuration and after retrofit with an unrestrained stepping rocking wall. The wall is modeled to permit uplift and alternating corner rocking, activating gravity-driven recentering without vertical post-tensioning or supplemental damping. Structural response is assessed under suites of recorded ordinary and pulse-like ground motions representative of near-fault seismic hazards.

The results show that the stepping rocking wall consistently reshapes the deformation mechanism from drift-localized response to a predominantly first-mode-dominated pattern. Peak interstory drifts are reduced in the most highly demanded stories, and residual drifts are substantially suppressed. Weak-story behavior is quantified using a drift concentration factor (DCF) defined as the ratio of peak story drift to height-averaged drift. The retrofit reduces mean DCF values by approximately 20% in the 9-story frame and 35–40% in the 20-story frame, indicating near-uniform drift distribution even under pulse-like excitation.

Residual drift demands are interpreted using FEMA P-58 repairability thresholds. The stepping rocking wall eliminates irreparable residual-drift states in the 20-story frame and reduces all residual drift in the 9-story frame to negligible levels, demonstrating a marked improvement in post-earthquake functional recovery.

To generalize beyond recorded motions, transient drift spectra are developed using symmetric and antisymmetric Ricker wavelets with controlled pulse period and amplitude. These spectra show that drift amplification peaks when pulse period approaches the fundamental structural period and that the rocking wall is particularly effective in suppressing these long-period demands through uplift-dominated response and geometric recentering. Overall, the results highlight uplift kinematics as a key mechanism for mitigating pulse-induced drift localization and improving seismic resilience in tall frames.

Speaker



Mehrdad Aghagholizadeh

Assistant Professor | Loyola Marymount University

ID 941: Predicting Limiting and Mobilized Earth Pressure in a Rocking Backfill Retained by a Rigid Wall

10:50 AM – 11:10 AM

Author(s): Kamyar Sadeghi, University of Colorado Boulder; Srikanth Madabhushi, University of Colorado Boulder

Retaining walls are used to support soil masses and maintain differences in ground elevation in civil and geotechnical engineering applications. However, under dynamic loading conditions—such as seismic excitation—they may be susceptible to failures or significant deformations due to soil–structure interaction effects. In both static and dynamic analyses of retained soil, it is common to estimate the limiting horizontal soil pressures by multiplying earth pressure coefficients with the geostatic vertical stresses. In reality, while the horizontal soil pressures are bounded by plastic failure they will be mobilized proportional to relative displacement between the wall and boundary. Furthermore, recent studies have found that purely horizontal ground shaking can nevertheless induce vertical accelerations, leading to temporal variations in vertical stress due to local or global rocking mechanisms. As a result, the vertical stress at a given depth is not constant but may vary as a function of the characteristics of the input motion. In this study, an analytical approach is investigated to try and capture rocking of a soil body retained by a rigid wall based on inertial considerations as well mobilization of horizontal pressures between plastic limit states. A Duncan-Chang constitutive model is used to translate estimates of soil strains inferred from shear vibration modes to mobilized horizontal stresses. These are then combined with the dynamic vertical effective stresses to estimate time-varying horizontal stresses imparted by the soil to the wall. Comparison of these against effective stress based dynamic finite element analyses shows how the proposed simplified analytical predictions of the rocking and lateral stress mobilization are effective to capture many salient aspects of the horizontal dynamic stresses in the retained soil, though subtleties due to the transients and elastoplastic soil response are missed. Overall, the importance of accounting for rocking mechanisms in the dynamic analyses of retained soil is highlighted, as well as paths forward to analytically approximate these behaviors without necessitating more involved finite element analyses for geotechnical earthquake engineering practice.

Speaker



Kamyar Sadeghi

University of Colorado Boulder

MS 057: Performance Evolution and Control of Concrete Structures

9:30 AM – 11:30 AM | Location: KTCH 1B87

Chair(s): Chao Jiang; Yao Wang; Jinliang Liu

Moderatorss



Chao Jiang

Associate Professor | Tongji University



Yao Wang

assistant professor | UT Arlington

ID 119: Assessing flexural bearing capacities for existing corroded RC beams based on Bayesian updating

9:30 AM – 9:50 AM

Author(s): Chao Jiang, Tongji University; Ting-Yu Xiang, Tongji University; Xiang-Lin Gu, Tongji University; Pei-Xi Yu, Tongji University

Corrosion of steel bars is the primary cause for performance degradation of reinforced concrete (RC) structures. Under time-varying environments, non-uniform corrosion of steel bars inside concrete will happen, which will lead to stochastic performance degradation of RC members and the transformation of failure modes, thus bringing significant uncertainty in predicting the mechanical performance of an RC member. Therefore, in this paper, a method based on Bayesian updating was proposed to predict normal-section bending bearing capacities of corroded RC beams. Prior distribution of corrosion degree was estimated from measured samples while likelihood function was established by combining the theoretical formula and observed data for short-term bending stiffness, then posterior distribution was obtained from Bayes updating. Sampling corrosion degree from the updated posterior distribution, the corresponding probability distribution of normal section bending bearing capacities could be obtained by utilizing the random stress-strain relationship of corroded steel bars. Meanwhile, the bending tests on corroded RC beams were conducted and results showed that both the bending capacity and the bending stiffness of a corroded RC beam decreased with developing of corrosion, the failure mode might transform while corrosion reached a critical level. The relevance between bending stiffness and corrosion degree validates the feasibility of establishing likelihood function from bending stiffness. Comparing the calculation and the experimental results for eight testing beams in this paper and another 28 testing beams from the literature, it was demonstrated that the proposed method is reliable.

Speaker



Chao Jiang

Associate Professor | Tongji University

ID 346: Physicomechanical Corrosion Precursors for Early Warning of Chloride-induced Corrosion in Reinforced Concrete

9:50 AM – 10:10 AM

Author(s): Yao Wang, UT Arlington; Shuhai Wu, UT Arlington

Chloride-induced corrosion is a primary cause of durability degradation in reinforced concrete infrastructure. Existing structural health monitoring approaches largely rely on the detection of visible cracking, at which point damage is irreversible and remediation effectiveness is limited. To enable proactive intervention, this study develops an early-warning framework grounded in the fundamental mechanisms of chloride-induced corrosion. A fully coupled thermo-hydro-chemical transport model is established to predict the internal evolution of temperature, humidity, and chloride concentration within concrete. Machine learning techniques are further employed to synthesize existing experimental and field data and to identify critical thresholds of governing factors that trigger corrosion-induced cracking. By defining quantitative "red-line" criteria for these key parameters, the proposed framework enables early warning of chloride-induced corrosion prior to crack initiation, offering a more effective strategy for extending the service life of reinforced concrete structures.

Speaker



Yao Wang

assistant professor | UT Arlington

ID 587: Influence of Coarse Aggregate Species on the Durability of Performance-Based Concrete Mixes in Arkansas

10:10 AM – 10:30 AM

Author(s): Shuyah Tani Aurore Ouoba, University of Arkansas - Fayetteville; Cameron Murray, University of Arkansas - Fayetteville

Contributing to more than half of the concrete volume, coarse aggregates are often treated as interchangeable inert materials in transportation-related design specifications. However, they strongly influence the durability and long-term performance of concrete. In fact, recent durability challenges in Arkansas bridge decks have prompted a re-evaluation of aggregate selection practices. This study investigates how four coarse aggregate species commonly used in Arkansas affect concrete durability by examining shrinkage, freeze–thaw resistance, mixture resistivity, and alkali–silica reactions (ASR).

The aggregates were first characterized for physical, mechanical, and chemical properties, including absorption, specific gravity, soundness, and petrographic analysis. Their susceptibility to ASR was evaluated using multiple methods: ASTM C1260 Accelerated Mortar Bar Test, AASHTO T380 Miniature Concrete Prism Test, a modified version of AASHTO T380, and the recently proposed Turner-Fairbank Aggregate Susceptibility Test (TFAST). TFAST is an accelerated test that measures aggregate dissolution in an alkaline solution using inductively coupled plasma analysis to identify released elements and assess the presence of reactive phases within 21 days. Results from these tests were compared to assess the consistency of their classification of aggregate reactivity and to identify potential causes of misidentification in the traditional expansion-based test methods.

Concrete mixtures were produced using each coarse aggregate with varying cementitious contents and optimized combined gradations. The mixtures were evaluated for fresh properties, including air content and Super Air Meter (SAM), compressive strength, modulus of elasticity, electrical bulk resistivity, hardened air-void parameters, and resistance to freezing and thawing. Initial observations from ongoing testing suggest that aggregate species significantly influence formation factor, air-void quality, and freeze–thaw durability, even when mixtures satisfy the prescribed gradation requirements. Differences observed between ASTM C1260 and TFAST classifications further highlight the need for multi-method ASR assessment and improved specification guidance. The experimental part of the research is still ongoing, and complete results, including correlations between aggregate characteristics, ASR susceptibility, and durability performance, will be presented at the conference.

This study aims to advance performance-based concrete specifications by incorporating aggregate mineralogy and intrinsic characteristics into mixture design. While focused on Arkansas materials, the outcomes will provide a model that other agencies can adopt, linking locally available aggregate sources to measured durability indicators rather than relying solely on prescriptive gradation limits.

Speaker



Shuyah Tani Aurore Ouoba

PhD Candidate | University of Arkansas-Fayetteville

ID 612: Post-Failure Backcasting of Aging Viscoelastic Response in Concrete Structures

10:30 AM – 10:50 AM

Author(s): Naiara Tonin, University of Colorado Boulder; Mija Hubler, University of Colorado Boulder

Existing models for concrete viscoelasticity are predominantly empirical, rely on approximate aging representations or historical records that are typically unavailable, and provide no systematic capability for post-failure analysis. This work proposes a unified theoretical and experimental forensic framework for backcasting sustained stress histories and time-dependent deformation under incomplete information. The framework is rigorously derived from the Boltzmann Superposition Principle (BSP) and generalized to aging viscoelastic materials through age-dependent hereditary kernels that explicitly account for the loss of time-translation invariance. Relaxation and compliance are coupled through an aging reciprocity relation formulated as a Volterra equation, enabling closed-form solutions for instantaneous, delayed, and recovered strain components under unknown loading histories. On this theoretical basis, a forensic backcasting methodology is developed to reconstruct historical stress states and viscoelastic strain evolution from short-term reloading tests using limited experimental data. The proposed framework establishes a mathematically consistent, physics-based foundation for structural backcasting and post-failure assessment when prior records are missing.

Speaker



Naiara Tonin

PhD in Structural Engineering & Mechanical Engineering | University of Colorado Boulder

ID 726: Corrosion of Carbon Steel Exposed to Superabsorbent Polymers in Chloride-Contaminated Cement Pore Solution

10:50 AM – 11:10 AM

Author(s): Muhammad Rafiul Mahdi, Arizona State University; Narayanan Neithalath, Arizona State University; Ravi Kiran, Arizona State University

Superabsorbent polymers (SAPs) have hydrophilic polymer chains capable of absorbing and retaining large quantities of aqueous solutions relative to their own mass while remaining insoluble. Recently, SAPs have been used as internal and external curing agents, air-entrainment additives, and deicing additives in civil engineering applications. In particular, SAPs are introduced into concrete at low dosages as internal curing agents to mitigate autogenous shrinkage by releasing water. However, the water-absorbing nature and cross-linked chemical structure of these polymers have the potential to modify the pore solution chemistry and liquid transport mechanisms in concrete. This alteration may significantly influence chloride concentration, thereby affecting the rebar corrosion process. Despite the growing use of SAPs in concrete, their direct influence on steel corrosion under chloride-contaminated conditions remains insufficiently understood, revealing a research gap that this study seeks to address. The objective of this research is to analyze the corrosion rate and mechanism of carbon steel exposed to saturated SAPs and the unabsorbed fluid from the SAP-mixed chloride-contaminated cement pore solution. This study aims to evaluate the corrosivity of two commercially available SAPs, SNa (sodium salt of crosslinked polyacrylic acid) and SK (potassium salt of crosslinked polyacrylic acid/polyacrylamide copolymer), in chloride-contaminated cement pore solution (CCPS). For this purpose, a 1.0% addition of these SAPs to CCPS was investigated for two cases, filtered and unfiltered solutions. The corrosion behavior of carbon steel samples is then quantified by conducting potentiodynamic polarization (PDP) and linear polarization resistance (LPR) tests. Inductively coupled plasma–optical emission spectroscopy (ICP-OES) was performed to determine ionic concentrations in the test solutions and quantify changes in pore-solution chemistry resulting from the addition of SAPs. The preliminary results from polarization tests indicate that instantaneous corrosion in an unfiltered solution is much lower than in a filtered solution, due to the higher solution resistance in both SAPs. For SAP SNa, the corrosion rate decreased by 92.50% in filtered solutions and by 95.00% in unfiltered solutions, whereas SAP SK resulted in corrosion rate reductions of 75.30% and 81.17% in filtered and unfiltered solutions, respectively, indicating a significant corrosion-inhibiting effect under both conditions.

Speaker



Muhammad Rafiul Mahdi

Graduate Research Associate | Arizona State University

ID 305: Information-Conditioned Probabilistic Capacity Assessment of Pyrrhotite-Affected Concrete Walls

11:10 AM – 11:30 AM

Author(s): mohammad amin hariri-ardebili, NIST; Patrick Dixon, NIST; Golsa Mahdavi, AECOM; Surya Congress, Michigan State University

Pyrrhotite-bearing aggregates can trigger internal sulfate attack through oxidation, producing expansive reaction products, distributed microcracking, and progressive loss of stiffness in residential basement walls. Although inspection programs in northeastern Connecticut use crack observations to rate damage and prioritize replacement, translating these observations into structural capacity remains largely qualitative. This paper presents a probabilistic, mechanics-based computational framework to estimate the load–deformation response of pyrrhotite-affected concrete walls by combining field data, spatially variable material models, and nonlinear finite element (FE) analysis.

A representative basement wall of a pyrrhotite-affected home in Connecticut is used as a case study, with inputs from photogrammetry-derived crack maps and mechanical properties measured on extracted cores from recent NIST field campaigns. Across the dataset, intake dynamic Young's modulus spans roughly 1.5 GPa – 25 GPa, whereas compressive strength for a mechanically tested subset lies between 10.7 MPa – 22.1 MPa, indicating that deterioration can reduce stiffness more dramatically than strength. Deterioration is represented through a two-dimensional spatial distribution of degraded dynamic modulus $E_{dyn}(x)$ that is mapped onto a three-dimensional wall model. Core locations provide pointwise modulus measurements, and discretized crack segments add conditioning points; crack points are assigned severity-dependent modulus reduction factors.

Two complementary strategies are compared to construct $E_{dyn}(x)$: (1) conditional Gaussian random fields that generate ensembles of stochastic realizations consistent with the conditioning data and calibrated correlation lengths, and (2) Gaussian-process/ordinary-kriging interpolation that yields a best linear unbiased estimate. The heterogeneous fields are propagated through a 3D FE model subjected to vertical compression, sustained earth pressure, and a displacement-controlled reverse-cyclic lateral protocol to capture peak and post-peak behavior. Concrete is modeled with linear elasticity up to cracking and a rotating smeared-crack formulation with tension softening and compression hardening/softening.

Ensembles of capacity curves (base shear versus drift) quantify how pyrrhotite-induced heterogeneity reduces stiffness, strength, and deformation capacity and increases response variability. Probabilistic summaries include mean and mean $\pm$ one standard deviation capacity curves and drift-dependent standard deviation and coefficient of variation, enabling direct comparison among homogeneous, random-field, and kriging-based modeling cases. Homogeneous scaled-property models can provide broad bounds but do not reproduce the strong response asymmetry and localized crack widening observed in deteriorated walls, whereas random-field and kriging-informed heterogeneous models capture these features. The proposed workflow advances probabilistic, mechanics-based assessment of pyrrhotite-damaged concrete structures and supports more transparent decisions on repair, replacement, and risk communication.

Speaker



Amin Hariri

Researcher | NIST

MS 085: Seismic Isolation and Energy Dissipation Systems: Mechanics, Experiments, and Innovations — In Honor of Professor James M. Kelly (1935–2025)

9:30 AM – 11:30 AM | Location: GUGG 205

Chair(s): Dimitrios Konstantinidis; Nicos Makris

Moderator(s)



Dimitrios Konstantinidis

Associate Professor | University of California, Berkeley



Nicos Makris

Professor | Southern Methodist University

ID 946: Effects of Reinforcement Thickness on the Response of Elastomeric Seismic Isolators

9:30 AM – 9:50 AM

Author(s): Eduardo J. Montalto, University of Colorado Boulder; Dimitrios Konstantinidis, University of California, Berkeley

Elastomeric seismic isolators are subjected to large transient compressive loads during earthquake events because of overturning moments and vertical ground motion. The lateral response of the bearings is noticeably affected by these vertical loads and, under extreme conditions, the bearings may become laterally unstable, representing a primary failure mode of these devices. Traditionally, the isolator steel reinforcing shims have been assumed to behave as flexurally rigid both in research and engineering practice, and their deformation has been neglected in the assessment of the coupled lateral and vertical response of elastomeric seismic isolators. Consequently, analytical and numerical models of elastomeric bearings do not account for steel shim deformation, and steel shim design is based solely on strength considerations aimed at preventing yielding under isolator compression. The belief that steel shim deformation does not play a role in the bearing response stems from previous experimental studies using reduced-scale specimens. In these studies, the specimens preserved important geometric properties, including the first and second shape factors, but they used steel shims typical of full-scale bearings. The specimens featured proportionally much thicker reinforcement, with shim slenderness (diameter-to-thickness) ratios close to 50, while real elastomeric isolators commonly use ratios in the 200–300 range. Consequently, shim bending effects were largely unobserved in these studies. However, recent numerical studies have shown that the lateral response and stability limits are influenced by the reinforcement slenderness ratio, with the stability domain decreasing as this parameter increases, signaling that reinforcement bending affects the response of the bearings. This work presents results from an experimental study conducted to quantify the effect of shim bending on the lateral response and stability limits of elastomeric isolators. The experimental campaign involved testing reduced-scale specimens with varying reinforcement thicknesses but otherwise identical designs. Component-level tests were used to determine the stability domain of the bearings by subjecting them to lateral deformations at varying compressive loads. Additionally, shake-table tests of a rigid base-isolated platform were performed to evaluate differences in the dynamic stability and damage exhibited by the isolators with different shim thicknesses.

Speaker



Dimitrios Konstantinidis

Associate Professor | University of California, Berkeley

ID 213: Design of Friction Dampers for a 3D Long-Period Base Isolation System

9:50 AM – 10:10 AM

Author(s): Donggeun Kim, Seoul National University; Seungho Baek, Seoul National University; Inje Sung, Seoul National University; Minyeop Kim, Seoul National University; Giheon You, Seoul National University; Wonhui Goh, Seoul National University; Chunghyun Lee, Seoul National University; Yunbyeong Chae, Seoul National University

This study addresses the design of a friction damper as a supplementary energy dissipation component for a long-period base isolation system intended to protect critical electronic equipment. Long-period isolation systems are effective in reducing acceleration response, while displacement demand also requires careful consideration in design. Friction dampers are attractive as supplementary devices due to their simple configuration and ease of maintenance; however, their effective application depends on overall damper design, including how frictional resistance is generated and stably maintained during system motion.

A uniaxial friction damper was designed for a long-period isolation system with target fundamental periods of approximately 1.5 s for both horizontal and vertical directions. The damper applies a prescribed normal force to the friction interface through spring compression between a linear shaft and surrounding metallic plates. Design constraints were defined based on an upper mass on the order of 200 kg and an allowable displacement of approximately 100 mm. Numerical simulations were conducted to estimate the required friction force under beyond-design-level seismic excitations. The design concept was implemented in a prototype and evaluated through preliminary characterization tests, confirming stable frictional resistance and consistent hysteretic behavior. Further validation will be conducted through shake-table testing after integration into the isolation system.

This work was supported by KOREA HYDRO & NUCLEAR POWER CO., LTD (No. 2024-Tech-07)

Speaker



Donggeun Kim

Seoul national university

ID 245: Rocking Isolation of Bridge Piers with Energy Dissipation Devices: Mechanics and Lessons from the South Rangitikei Rail Bridge

10:10 AM – 10:30 AM

Author(s): Mehrdad Aghagholizadeh, Loyola Marymount University; Nicos Makris, Southern Methodist University

Rocking isolation represents one of the earliest seismic isolation strategies, exploiting uplift and controlled rocking to limit force transmission while ensuring gravity-driven recentering. This study investigates the nonlinear seismic response of rocking bridge piers supplemented with hysteretic and viscous energy dissipation devices, with particular emphasis on the mechanics governing their effectiveness and limitations under different ground motion characteristics.

The study first derives the equations of motion for slender free-standing rocking columns equipped with supplemental damping and examines how hysteretic and viscous dissipation mechanisms modify rocking stability, energy balance, and peak response. Parametric analyses using recorded earthquake motions and idealized pulse-type excitations reveal that while supplemental damping generally suppresses rocking response, isolated cases exist in which damping can marginally amplify peak rotations due to complex interactions among gravity, inertia, and damper forces.

These mechanics are illustrated through a detailed case study of the South Rangitikei Rail Bridge in New Zealand, a seminal example of rocking isolation designed in the late 1960s and enhanced with torsionally yielding steel-beam dampers developed under the influence of Professor James M. Kelly's pioneering work. Nonlinear response-history analyses demonstrate that the 72-m tall stepping piers exhibit exceptional seismic stability, maintaining controlled rocking and recentering even when subjected to ground motions far exceeding those considered in the original design.

The findings underscore the enduring relevance of rocking isolation as a resilient seismic protection strategy and highlight the need for careful damper selection informed by ground motion kinematics. By revisiting one of the earliest full-scale implementations of rocking isolation, this work connects foundational mechanics to contemporary performance-based design and honors Professor Kelly's lasting contributions to seismic isolation and energy dissipation systems.

Speaker



Mehrdad Aghagholizadeh

Assistant Professor | Loyola Marymount University

ID 924: Re-Envisioning Mechanical Models for Elastomeric Seismic Isolators

10:30 AM – 10:50 AM

Author(s): Eduardo Montalto, University of Colorado Boulder; Dimitrios Konstantinidis, University of California, Berkeley

Traditionally, elastomeric isolators are analytically treated as beams that allow shear but not cross-sectional deformations, and where second-order geometric nonlinearities are considered. The corresponding effective cross-sectional rigidities are obtained from an approximate analytical homogenization under linear elastic conditions. This analytical model captures the isolator response under small deformations, as well as some nonlinear phenomena, such as buckling under pure compression. However, elastomeric seismic isolators exhibit significant geometric nonlinearities that strongly couple their lateral and vertical responses under large deformations, and numerical models are required to represent this behavior. Currently, the most widely used numerical models are semi-empirical, treating the elastomeric isolator as a rigid element connected by discrete springs whose properties are heuristically manipulated to capture fundamental behaviors, such as buckling. Despite their usefulness, these models cannot capture localized effects in the bearing, an present difficulties for incorporating non-standard boundary conditions. This study introduces a fully mechanical two-scale modeling framework for elastomeric seismic isolators that explicitly accounts for the large deformation response in the bearings. At the structural scale, the isolator is treated as a one-dimensional geometrically exact rod with cross-sectional distortions. The rod's constitutive properties are determined via the computational homogenization of a mesoscopic unit cell, comprising a single rubber layer and two half-thickness reinforcement layers, using finite elements. To ensure computational efficiency for use in structural simulations, a surrogate constitutive model is trained to represent the homogenized response obtained from the offline mesoscale simulations. The proposed model improves the prediction of local stresses relevant to rubber cavitation and captures the flexural response of the reinforcement shims. Furthermore, it easily accommodates non-standard boundary conditions, including supports that allow rotation. The proposed model is validated against results from high-fidelity finite element simulations and an extensive experimental campaign that included component-level tests and shake-table tests. The two-scale modeling framework is a rational extension of the classical beam model for elastomeric isolators: bearings are now treated as geometrically exact rods with warping, and the effective constitutive properties are determined via computational homogenization to account for both material and geometric nonlinearities.

Speaker



Eduardo Montalto

Assistant Professor | University of Colorado Boulder

ID 207: Enhanced Characterization of Friction Pendulum Bearings Using Advanced Axial Force Control Method

10:50 AM – 11:10 AM

Author(s): Chunghyun Lee, Seoul National University; Yunbyeong Chae, Seoul National University

Friction Pendulum (FP) bearings have become a widely adopted strategy for the seismic isolation of critical infrastructure, particularly in high-seismicity regions such as California and Japan. Accurate characterization of these bearings is essential for reliable seismic performance assessment; however, the behavior of FP bearings is fundamentally non-linear and highly sensitive to the applied axial load. Consequently, maintaining precise control over the axial load during experimental evaluation is critical. Conventional testing methods utilizing hydraulic actuators often face significant challenges in this regard. Due to the sensitivity of force-controlled hydraulic systems to specimen displacement, standard controllers frequently struggle to decouple the vertical force application from the horizontal motion, leading to fluctuations that impede accurate experimental evaluation.

To address these limitations, this study establishes a robust experimental framework by adopting the D-ATS algorithm, a high-precision force control method. The primary objective of the D-ATS algorithm is to maintain a stable, constant axial load during the dynamic excitation of horizontal displacements, thereby eliminating the inaccuracies associated with traditional control methods. The experimental setup utilized a simplified shake table driven by 10 kN hydraulic actuators for horizontal displacement, while a 500 kN hydraulic actuator applied the vertical load. The horizontal restoring force of the FP bearing was recorded using a dedicated load cell.

To validate the efficacy of the proposed method, a comprehensive parametric study was conducted. Unidirectional triangular lateral wave excitations were applied to the FP bearing while varying the sliding velocity, axial load, and maximum displacement amplitudes. For comparative analysis, a subset of these tests was repeated using a conventional Proportional-Integral-Derivative (PID) controller. The results demonstrated the clear superiority of the D-ATS algorithm, which maintained high-accuracy axial load control throughout the excitation. In contrast, the PID controller exhibited unstable performance and consistently induced higher restoring forces, leading to significant measurement errors. Using the proposed methodology and a novel test setup, this study enables more accurate and reliable identification of FP bearing characteristics.

Speaker



Chunghyun Lee

Ph.D. Student | Seoul National University

ID 688: A Modified Weighted Adaptive Constrained Unscented Kalman Filter for Shape Memory Alloy Wire Dampers in Real-Time Hybrid Simulation

11:10 AM – 11:30 AM

Author(s): Florian Kolisch, RWTH Aachen University; Alejandro Palacio-Betancur, MTS Systems Corporation; Sven Klinkel, RWTH Aachen University

Real-time hybrid simulation (RTHS) in civil engineering has become an established tool for dynamic testing of time-dependent prototypes, such as new and innovative structural vibration control devices. For this purpose, finite element simulations are combined with physical testing of the prototypes in the laboratory, while the displacements and forces at the interface of the numerical and experimental substructures are calculated, measured, and synchronized. In this study, large-scale shape memory alloy (SMA) wire dampers (SMAWDs) are tested as the experimental substructure. While SMA materials are known for their superelasticity and theoretical ability to fully recover from large strains, continuous dynamic excitation produces residual deformations that progressively reduce wire tension. This wire slacking gives rise to a strongly nonlinear, frequency-dependent response, especially during the transition from tension to compression. In addition, the high stiffness, low mass, and pronounced internal friction of SMAWDs, coupled with the mounting system and hydraulic actuator, amplify high-frequency dynamics within the experimental substructure. While RTHS enables the evaluation of SMAWDs in full-scale structures under various excitations, such as wind and earthquakes, these characteristics introduce significant numerical challenges. For the considered full-scale steel frame numerical model, the resulting high noise-to-signal ratio at frequencies close to the numerical natural frequencies degrades the stability, accuracy, and reliability of the RTHS with SMAWDs, as the measured forces are directly fed back into the numerical simulation. To address these challenges, we propose a Modified Weighted Adaptive Constrained Unscented Kalman Filter (MWACUKF) that incorporates state-dependent constraints to correctly represent slacking and superelastic regions, allowing reliable system identification of the SMAWDs within the RTHS framework. This approach enables accurate reproduction of the complex hysteretic behavior of the SMAWDs, including wire slacking, while effectively reducing high-frequency noise in the feedback loop. Comparative RTHS studies demonstrate that the MWACUKF significantly improves force-feedback quality and numerical stability, thereby extending the applicability of RTHS to highly nonlinear, state-dependent damping devices.

Speaker



Alejandro Palacio

System Integration Engineer | MTS Systems Corporation

MS 071: 5th Mini-Symposium on civil infrastructure in a changing climate: from nonstationary risk assessment to developing adaptation strategies

9:30 AM – 11:30 AM | Location: ECON 119

Chair(s): Eun Jeong Cha; Abdollah Shafieezadeh; Michele Barbato; Alexandros Taflanidis

Moderatorss



Alexandros Taflanidis

Professor | University of Notre Dame



Michele Barbato

Professor | University of California, Davis

ID 196: Climate-Informed Geotechnical Assessment of Rainfall-Induced Landslide Hazards for Road Network Resilience in Turin, Italy

9:30 AM – 9:50 AM

Author(s): Marco Civera, Department of Structural, Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy; Seyedmostafa Moeini, Department of Structural, Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy; Maria Romana Alvi, Department of Structural, Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy; Fabrizio Aloschi, Department of Structures for Engineering and Architecture, University of Naples "Federico II", Via Claudio 21, 80125 Naples, Italy; Andrea Prota, Department of Structures for Engineering and Architecture, University of Naples "Federico II", Via Claudio 21, 80125 Naples, Italy

Climate change is intensifying the frequency and magnitude of rainfall events, both extreme and regular ones, leading to more severe hazard conditions over the long run. In this regard, rural road infrastructure in hilly and mountainous regions is particularly vulnerable to rainfall-induced landslides (RILs), as evolving precipitation regimes interact with heterogeneous soil properties and complex terrain morphology, affecting slope stability and the resilience of road networks (RNs). Thus, higher-intensity hazards result in greater risks, even without accounting for the ever-growing vulnerability of ageing construction materials.

This study presents preliminary results from a GIS-based, physically informed framework for assessing rainfall-driven landslide hazards along road infrastructure, to support climate-adaptive risk assessment and resilience-oriented planning.

The methodology is applied to a representative hilly and forested area in the Piedmont Region (northwestern Italy), between the large metropolitan area of Turin and the small town of Pino Torinese, along a high-traffic road (Strada Statale Padana Inferiore – SS10), and smaller alternative routes. High-resolution topographic data, spatially distributed geotechnical parameters, and regional rainfall statistics are integrated within a unified modelling environment.

Rainfall infiltration is explicitly modelled using a steady-state hydrological formulation, enabling estimation of the saturated soil depth as a function of rainfall intensity, soil porosity, hydraulic conductivity, and other geotechnical parameters. This infiltration depth is incorporated into a physically based slope stability model to compute the Factor of Safety (FS) under rainfall-induced conditions. A viewshed-based terrain classification is employed to distinguish uphill and downhill slope sectors relative to road alignments, allowing targeted assessment of slope failures most likely to disrupt infrastructure through debris accumulation or loss of ground support. Results identify several zones prone to instability, some of which intersect critical road segments.

To account for climate nonstationarity, the framework is applied not only to historical and design rainfall events but also to projected rainfall intensities derived from climate change forecasts for the same spatial domain. This enables assessment of how anticipated increases in rainfall magnitude may alter stability conditions and expand zones susceptible to failure; the results indicate a systematic reduction in stability margins and a widening of hazardous areas, underscoring the sensitivity of geotechnical systems to climate-driven changes in precipitation. Quantitative metrics to evaluate shifts in landslide-triggering thresholds under future climate scenarios are also estimated.

In conclusion, the proposed framework supports nonstationary risk assessment and informs adaptation strategies such as updated early-warning thresholds, prioritised slope stabilisation, and resilience-based infrastructure management. The approach is transferable to other landslide-prone regions and contributes to the development of climate-resilient transportation networks.

Speaker



Marco Civera

Tenure-track Assistant Professor | POLITECNICO DI TORINO

ID 41: Using an Informational Design Approach for Civil Engineering Project Planning under Climate Change

9:50 AM – 10:10 AM

Author(s): Richard Koehler, Visual Data Analytics, LLC

Climate change affects multiple types of engineered infrastructure. Engineers are encouraged to engage in cooperative research involving scientists from multiple disciplines to gain an understanding of the magnitudes of future extremes and their consequences [1]. Beyond this guidance, it is important that with increasingly sophisticated risk analysis of engineering projects, an assessment of environmental input data with similarly advanced techniques should be included to identify relevant patterns.

Specifically, the research presented here demonstrates novel ways to increase the understanding of the hydrologic regime, critical when designing and monitoring engineering projects. By using informational design concepts and a geo-temporal information system (GTIS), the following three data visualization and analysis techniques are possible.

1 - The raster hydrograph. This dual time scale graph simultaneously displays daily, weekly, monthly, seasonal, annual and inter-annual flow patterns on a single plot, helping to identify climate change signatures.

2 - The enhanced flow duration curve (eFDC). The traditional FDC has no chronological order information, limiting the ability to identify climate change within the streamflow record. The eFDC solves this problem by plotting a dQ/dt point cloud around the traditional FDC [2]. This results in new ways to visualize and identify changes in flow patterns between comparison periods.

3 - The dQ/dt matrix. An extension of the eFDC, this matrix displays and quantifies all hydrologic conditions within the daily flow record. Data self-sorts within the matrix, showing regions of increasing flow ($dQ/dt > 0$), steady flow ($dQ/dt = 0$), and decreasing flow ($dQ/dt < 0$). The number and degree of discharge conditions are detailed, allowing for a Markov transition matrix approach to summarize streamflow changes and to facilitate future Markov chain simulations.

Other benefits include more efficient, higher resolution model calibrations and sensitivity analyses, greater plot customization, and improved communication of results to a wider audience.

[1] Committee on Adaptation to a Changing Climate, June 2015. Adapting infrastructure and civil engineering practice to a changing climate. American Society of Civil Engineers.

[2] Koehler, R., March 2025, How to modernize the flow duration curve, Staying Sharp, CE Magazine, American Society of Civil Engineering.

Speaker



Richard Koehler

CEO | Visual Data Analytics, LLC

ID 163: Probabilistic Stress Testing of National-Scale Power Grids under Climate Change with Physically and Operationally Consistent Dispatch

10:10 AM – 10:30 AM

Author(s): Uichan Seok, Department of Civil, Urban and Environmental Engineering, Seoul National University; Ji-Eun Byun, James Watt School of Engineering, University of Glasgow; Junho Song, Department of Civil, Urban and Environmental Engineering, Seoul National University

National energy grids are increasingly exposed to climate-driven stress events, as growing renewable penetration makes power system performance more sensitive to weather conditions. From a modelling perspective, the spatiotemporal variability of climate leads to strong regional differences in renewable generation and electricity demand during extreme events. These differences interact across the transmission network and produce system-wide stress patterns, which require many realizations of correlated extremes for reliable assessment. However, existing probabilistic climate projection datasets often provide limited ensemble sizes and insufficient characterization of such dependence structures. From a stress-testing perspective, many adequacy assessments focus on the occurrence of energy shortfalls as a key indicator. This approach can overlook prolonged, continuous shortfalls arising from sustained correlations across consecutive days, thereby limiting insight into system behaviour during sustained climate-driven stress.

This study addresses these limitations by developing a climate-uncertainty-aware stress testing framework with two coupled components. First, to resolve the modelling limitation, we train a denoising diffusion probabilistic model on climate projection data to generate climate-driven inputs for renewable generation and demand. The generated scenarios preserve spatial and temporal correlations across regions and provide a larger set of coherent extreme realizations for system assessment. Second, to resolve limitations in the stress testing, we evaluate each scenario using a DC optimal power flow formulation that explicitly represents operation under extreme conditions. Long-duration storage is included as a bus-level resource to cover prolonged shortfalls that exceed the capacity of short-term balancing resources. Storage is modelled to support deficit periods through controlled discharge while also absorbing surplus renewable generation when available. Operational priorities are represented through a three-step lexicographic optimization structure that first minimizes energy shortfalls and then produces physically interpretable storage charging and discharging decisions.

The proposed framework enables national-scale stress testing under climate uncertainty with correlated extreme inputs and operationally consistent system response, which is particularly important for systems with high renewable penetration. The resulting assessments move beyond shortfall occurrences and characterize how severe and persistent shortages emerge and propagate across a network. This stress-testing capability also provides a coherent basis for subsequent studies in which operational performance under climate-driven extremes is integrated into expansion planning and infrastructure investment decisions.

Speaker



Uichan Seok

Graduate Student | Seoul National University

ID 35: Scenario-Aware Bayesian Optimization for the Optimal Design of Integrated Gray–Green Stormwater Systems

10:30 AM – 10:50 AM

Author(s): Yiyi Zhang, University of Texas at Arlington; Jinzhu Yu, University of Texas at Arlington

Increasingly intense and frequent rainfall events are elevating urban flood risks and causing significant socioeconomic impacts. In response, cities are adopting hybrid drainage systems that integrate gray infrastructure with green stormwater solutions (e.g., permeable pavements) because such systems offer improved flood mitigation and water-quality performance under budget constraints.

However, determining the optimal spatial allocation and sizing of gray–green components remains challenging due to the high-dimensional design space, nonlinear system behavior, and the computational burden of hydraulic simulations under diverse precipitation scenarios.

In this work, we develop a scenario-aware Bayesian Optimization framework that jointly minimizes lifecycle cost and overflow volume across multiple rainfall scenarios. The framework constructs a scenario-average GP surrogate to efficiently approximate system performance under precipitation uncertainty, thereby enabling rapid exploration of the design space with far fewer hydraulic simulations. Additionally, we evaluate the robustness of the scenario-average solution by quantifying its performance variance across rainfall scenarios.

Comparative analysis with conventional genetic algorithms demonstrates that the proposed approach achieves superior computational efficiency and solution quality across various rainfall scenarios. This research advances a data-efficient decision-support tool for urban planners and engineers in designing stormwater systems under future climate uncertainty.

Speaker



Jinzhu Yu

Assistant Professor | University of Texas at Arlington

ID 307: Integrating agent-based and life-cycle modeling for system-of-systems coastal adaptation assessment

10:50 AM – 11:10 AM

Author(s): Mohamed Abdelhafez, Department of Civil and Environmental Engineering, Vanderbilt University; Hussam Mahmoud, Department of Civil and Environmental Engineering, Vanderbilt University; Bruce Ellingwood, Department of Civil and Environmental Engineering, Colorado State University

Coastal communities face increasing vulnerability to sea-level rise (SLR) and hurricane-induced storm surge, posing growing risks to interconnected social, economic and physical infrastructure systems. Conventional coastal protection strategies often prioritize individual assets or hazard metrics, limiting their ability to capture how vulnerabilities emerge across interacting systems prior to extreme events. Nature-based (green) solutions (NbS) and hybrid strategies offer promising adaptation pathways, yet their system-level implications remain insufficiently evaluated within integrated, precautionary decision frameworks.

This study presents a modeling framework that integrates Agent-Based Modeling (ABM) with Life Cycle Assessment (LCA) to assess engineered, nature-based, and hybrid coastal adaptation strategies under projected SLR and storm surge scenarios in a changing climate. The ABM represents coastal communities as a system of systems, capturing interdependencies between the built environment (buildings), lifeline infrastructure (power networks), and access to critical services such as schools, hospitals, and emergency facilities (road networks). Rather than simulating post-event recovery, the framework focuses on identifying spatially heterogeneous vulnerability patterns that emerge from these interdependencies, enabling the detection of areas where cascading exposure and access constraints amplify risk prior to hazard occurrence. LCA enriches this analysis by quantifying life-cycle environmental impacts, including embodied greenhouse gas emissions, and supporting comparison of adaptation strategies beyond hazard reduction alone.

The framework is applied to Mobile and Baldwin Counties in Alabama, which border on the Gulf Coast. Coastal regions of these counties are densely populated and contain critical infrastructure, including extensive road networks, energy production and port facilities and economic assets situated in low-lying, flood-prone areas. Results demonstrate that while engineered (grey) infrastructure can reduce localized exposure, NbS and hybrid strategies may mitigate system-level vulnerability more sustainably by addressing interconnected risks with lower environmental burdens. The findings support integrated, system-informed adaptation planning aimed at reducing future vulnerability under deep uncertainties associated with a changing climate.

Speaker



Mohamed Abdelhafez

Postdoctoral Researcher | Vanderbilt University

ID 399: Improved Tropical-Cyclone Wind Hazard Assessment under Various Climate Change Scenarios

11:10 AM – 11:30 AM

Author(s): Jiahao Wang, Missouri University of Science and Technology; Norberto C. Nadal-Caraballo, Coastal and Hydraulics Laboratory, U.S. Army Engineer R&D Center; Yi Zhao, Missouri University of Science and Technology; Guirong Yan, Missouri University of Science and Technology; Ralf Toumi, Imperial College London; Brian Phillips, University of Florida

Given various uncertainties in future climate projections, constructing tropical-cyclone (TC) hazard curves over a spectrum of plausible climate scenarios is critical for supporting risk-informed resilience planning by coastal stakeholders. Most probabilistic TC hazard studies rely on synthetic storm catalogs, which are typically generated using full-track TC models with submodels that separately model TC genesis, track evolution, and intensity along the entire lifecycle of a TC. However, early stage modeling errors in the TC lifecycle can lower the modeling accuracy, and the full-track modeling approach requires extensive environmental inputs and considerable computation, while landfall behavior may still be captured with limited accuracy. To reduce the impact of these upstream uncertainties on TC hazard estimation, this study employs synthetic TC datasets produced by the ImpeRIal College Storm (IRIS) model. IRIS is designed to model only the evolution after the lifetime maximum intensity (LMI), focusing on the post-LMI phase rather than the entire storm lifecycle. Moreover, many prior hazard analyses adopted two-dimensional (2D) slab wind field models to reduce the computation cost. These slab models vertically integrate the boundary layer and treat winds as height invariant, which reduces the wind speed modeling accuracy and affects TC hazard assessment. To overcome the disadvantages of the existing datasets and models, in this study, the probabilistic TC hazard assessment is improved by using the newly developed synthetic TC datasets under various climate change scenarios and adopting a height-resolving three-dimensional (3D) wind-field model that incorporates spatial variability in land cover. TC wind speed hazard curves are then derived using the peak-over-threshold generalized Pareto distribution (POT-GPD) framework for multiple future climate scenarios at both state and city scales, enabling the following assessment of TC frequency and intensity changes in different climate scenarios. Overall, the results suggest that warmer climate scenarios are associated with intensified TCs and an increase in the total number of landfalling events, with the largest increases occurring among stronger TCs.

Speaker



Guirong Yan

Professor | Missouri University of Science and Technology

MS 079: Assessing Human-Infrastructure Interactions and their Performance

9:30 AM – 11:30 AM | Location: CHEM 140

Chair(s): Fernando Moreu; Haeyoung Noh; Katherine Flanigan; Yiwen Dong

Moderatorss



Fernando Moreu

Associate Professor | University of New Mexico



Katherine Flanigan

Assistant Professor | Carnegie Mellon University

ID 600: Fall Risk Estimation through Footstep-Induced Floor Vibrations

9:30 AM – 9:50 AM

Author(s): Adem Taiyr, Stanford University; Jessica Rose, Stanford University; Yiwen Dong, University of Illinois Urbana-Champaign; Haeyoung Noh, Stanford University

Falls are a leading cause of injury and death among older adults and individuals with neurological or musculoskeletal disorders, accounting for millions of injuries and hundreds of thousands of deaths worldwide each year. Fall risk estimation is based on biomechanical indicators such as lower-limb joint angles, minimum foot clearance (MFC), and Ground Reaction Forces (GRFs). However, existing clinical tools, such as force plates, wearable sensors, and cameras, are constrained by limited coverage, device-carrying, or privacy concerns, limiting their use in out-of-lab environments.

This work presents a fall risk estimation framework based on footstep-induced floor vibrations. Floor-mounted sensors record vibration signals generated by footsteps, which encode foot-floor interaction forces and leg motion. These signals are processed to reconstruct joint angles, MFC, and GRFs, which jointly determine fall risk. Our framework is contact-free, privacy-friendly, and provides wide coverage, making it suitable for out-of-lab settings, including homes and elder care facilities.

A major research challenge is that vibration signals contain gaps and masked portions: foot pushing off the floor (toe-off phase) generates weak vibrations often masked by subsequent footstep, while leg moving through the air (swing phase) produces no vibrations, making reconstruction of joint angles, MFC, and GRFs for the full gait cycle difficult. To recover these hidden dynamics, we analyze vibrations from three consecutive footsteps and exploit inter-footstep dependencies through an omni-scale convolutional neural network with kernel sizes spanning localized impacts and three-footstep dynamics.

A second research challenge is that fall risk arises from the complex interaction between motion- and force-based characteristics, so no single biomechanical parameter can reliably estimate it on its own. To address this, we compare deviations of joint angles, MFC, and GRF profiles from normal gait and integrate them in a unified model that emphasizes abnormal motion-force combinations, producing a calibrated fall risk.

We evaluate the framework on a real-world experiment with 20 participants and more than 3,000 footsteps with normal and abnormal gait. The framework achieves 90% accuracy in fall risk estimation, 90.5% accuracy in GRF estimation, mean absolute error (MAE) of 1.7 cm in MFC, and MAE of 6 degrees in joint angles. This performance is comparable to camera- and wearable-based systems and points to potential feature refinements.

Speaker



Adem Taiyr

PhD Student | Stanford University

ID 932: Disentangling and Classifying Real-Time Mobility Signals from Floor Vibration Mixtures

9:50 AM – 10:10 AM

Author(s): Yohanna MejiaCruz, Montana Technological University; Milad Roohi, University of Nebraska-Lincoln

Floor vibration technology has emerged as a promising approach for real-time monitoring of human walking patterns in home environments, without the need for wearable devices or cameras, thereby preserving privacy and requiring minimal user engagement. Nevertheless, accurately distinguishing signals associated with various movement types, especially when assistive devices are used, remains a significant challenge.

This study examines a signal-processing framework for distinguishing floor vibration signals arising from three primary mobility scenarios: unaided walking, walking with a cane, and wheelchair-assisted movement. Each scenario generates distinct vibration profiles due to variations in gait dynamics, load distribution, and contact points with the floor. The primary objective is to develop a method that does not depend on large datasets or complex, heavily parameterized machine learning models. Instead, the focus is on computationally lightweight, real-time signal processing techniques. The approach is evaluated on latency and accuracy metrics, which will serve as benchmarks for comparison with other models.

Independent Component Analysis (ICA) is employed as the primary method for source separation in this research. ICA decomposes recorded floor vibration mixtures into statistically independent components, hypothesized to correspond to specific mobility events. A central hypothesis is that a strategically distributed sensor array can yield sufficient independent observations to reliably separate mixed signals and recover underlying mobility signatures. The study analyzes both independent signals from isolated mobility events and mixed signals from concurrent activities to establish robust criteria for real-time identification of mobility types. Additionally, the study evaluates the impact of structural heterogeneity on vibration signatures from different assistive devices, including variability in floor materials, floor level, and architectural layouts.

This research advances the fields of ambient sensing and smart home monitoring by providing a scalable, unobtrusive approach to mobility assessment. The proposed method is particularly advantageous for aging populations and individuals with physical impairments. The findings represent progress toward reliable in-home monitoring systems that maintain user privacy and facilitate early detection of mobility changes.

Speaker



Yohanna M. Cruz

Assistant Professor (Incoming) | University of Central Florida

ID 244: A Human-in-the-Loop Augmented Reality Framework for Structural Health Monitoring

10:10 AM – 10:30 AM

Author(s): Priata Saha, University of New Orleans; Anika Tabassum Sarkar, University of New Orleans

Civil infrastructure asset management is predominantly informed by manual visual inspection, in which inspectors qualitatively assess structural conditions to ensure public safety. However, such assessments are subjective and exhibit significant inter- and intra-observer variability, especially for aging assets with complex, interacting damage mechanisms. Consequently, advancing the human–structure interface is critical for achieving reliable, human-centric structural health monitoring (SHM). Over the past decade, extended reality (XR) technologies have been explored in SHM to spatially register sensor data, damage indicators, and digital structural models onto physical assets, thereby enhancing situational awareness and streamlining inspection workflows. Prior studies have demonstrated the feasibility of different XR technologies for damage visualization, computer-vision-based crack detection, and remote expert guidance. Nonetheless, existing work has primarily emphasized technological demonstration and visualization capabilities, with limited quantitative assessment of how immersive interfaces affect human perception, decision-making processes, and inspection performance. Human inspectors are rarely modeled as explicit, measurable components of the SHM system, leaving a critical gap in understanding the human–infrastructure interaction.

This study addresses this gap by formulating a human-in-the-loop (HITL) SHM framework that conceptualizes inspectors as sensing and decision-making agents within the monitoring architecture. The framework leverages wearable augmented reality (AR) head-mounted displays integrated with machine learning models such as convolution neural network (CNN) to deliver spatially registered visualization of strain fields and damage states in real time during inspection. Controlled laboratory experiments on concrete specimens, complemented by field deployments on in-service structures, are conducted to compare baseline visual inspection with AR-assisted inspection. Human performance is quantitatively evaluated using metrics, including detection accuracy (correct identification of damage versus false positives and missed detections), intra-observer consistency (repeatability of assessments by the same inspector), inter-observer consistency (agreement among different inspectors), and inspection efficiency (time required to complete inspection tasks). Experimental results indicate that immersive AR visualization substantially reduces variability in human measurements, enhances consistency in damage identification, and improves global situational awareness relative to conventional practice. By embedding quantifiable human performance within SHM workflows, this work establishes a human-centric paradigm for infrastructure assessment in which inspectors transition from passive observers to active, information-rich sensing agents.

Speaker



Priata Saha

Graduate Student | University of New Orleans

ID 320: Integrating Human Machine Interfaces for Manipulator Path Planning and Object tracking

10:30 AM – 10:50 AM

Author(s): Hector Valenzuela, Smart Management of Infrastructure Laboratory (SMILab), University of New Mexico (Electrical and Computer Engineering); Fernando Moreu, Smart Management of Infrastructure Laboratory (SMILab), University of New Mexico (Civil Engineering)

Research on the incorporation of AR/VR technologies into manufacturing environments has demonstrated improvements in both productivity and safety. In parallel, the field continues to move toward increased automation through the use of robotic systems and manipulators. This work demonstrates the efficiency gains achieved by utilizing AR/VR-based interfaces for human–machine interaction (HMI) in the control of a robotic manipulator. Objects within the manipulator's trajectory are evaluated using static and dynamic path planning algorithms to calculate its trajectory appropriately. A custom AR/VR interface is presented to the user through a head-mounted display, enabling intuitive and informed interaction with the system. The overall objective of this approach is to enhance safety and productivity within the manufacturing workspace.

Speaker



Hector Valenzuela

Graduate Researcher | Smart Management of Infrastructure Laboratory (SMILab), University of New Mexico (Electrical and Com...

ID 393: Automated Rebar Spacing Inspection Integrating RGBD, BIM and Augmented Reality (AR)

10:50 AM – 11:10 AM

Author(s): Mahsa Sanei, University of New Mexico; Kira Kampschmidt, Albuquerque Academy High School; Fernando Moreu, University of New Mexico

Accurate inspection of reinforcing steel layout prior to concrete pouring is critical to the structural performance and durability of reinforced concrete systems. Conventional rebar inspection relies on manual measurements, two-dimensional drawings, and inspector experience, making the process time-consuming, error-prone, and physically demanding. This paper presents the development of an Augmented Reality (AR) based rebar inspection application that integrates depth sensing, Building Information Modeling (BIM), automated deviation detection, and optimized correction guidance to improve inspection efficiency and accuracy. The system captures as-built rebar geometry using an RGBD camera and reconstructs a three-dimensional point cloud, which is automatically processed to extract rebar centerlines and spacing measurements. The as-built model is registered to the design BIM model using QR-code-based spatial alignment, enabling direct geometric comparison in a shared coordinate system. Spacing compliance is evaluated according to ACI tolerance requirements, and violations are identified automatically. Results are visualized through a HoloLens 2 headset, where compliant and non-compliant spacing are color-coded and overlaid directly on the physical rebar. A greedy optimization algorithm computes a minimum-movement correction sequence, which is presented to the inspector as step-by-step AR guidance. The application supports real-time data exchange between computational processing and AR visualization through TCP/IP communication. Experimental validation in a controlled laboratory environment demonstrated 80% reductions in inspection time and unnecessary movement compared to traditional methods. The proposed AR rebar inspection system demonstrates the potential of combining automated sensing, optimization, and immersive visualization to enhance construction quality control while reducing inspector workload and decision uncertainty.

Speaker



Abhiram Reddy Chepyala

UNM

ID 571: Seal Whisker–Inspired Passive Marine Animal Monitoring through Wake-Induced Whisker Vibrations

11:10 AM – 11:30 AM

Author(s): Yuyan Wu, Stanford University; Sanjay Giridharan, Arizona State University; Leixin Ma, Arizona State University; Hae Young Noh, Stanford University

Marine animal monitoring is essential for assessing underwater ecosystem health, supporting fisheries management, and evaluating the impacts of offshore structures on marine life. Existing approaches primarily rely on active sonar, tagging, and camera-based systems. However, these methods can be harmful due to acoustic emissions, invasive to animals, or unreliable in turbid or low-light underwater environments. Despite the inherent challenges of marine animal monitoring, seals provide a compelling biological example of an effective passive sensing system for animal detection and tracking using their whiskers. Seal whiskers exhibit a distinctive wavy morphology that functions as a hydrodynamic noise filter. This specialized shape suppresses self-induced vortex shedding, thereby reducing flow-induced noise and enabling seals to effectively detect and track vortices generated by the swimming motions of prey. As a result, seals can sense weak hydrodynamic signals in noisy underwater environments, making their whiskers a highly efficient natural solution for passive marine animal monitoring.

Inspired by seal whiskers, we develop a noninvasive and lighting-robust marine animal monitoring method using a seal-whisker-inspired sensor. The underlying principle is that when a marine animal swims nearby, its body motion generates a wake and associated vortical structures in the surrounding water. These wake-induced flow disturbances propagate through the fluid and excite vibrations in the whisker structure. By analyzing these vortex-induced whisker vibrations, the presence of a passing marine animal can be detected. Moreover, different species exhibit distinct swimming kinematics, which generate characteristic wake patterns and, consequently, species-specific vibration patterns in the whisker. This enables not only detection but also species identification based on whisker vibration patterns.

A major research challenge is that marine animal-induced wakes are typically small in amplitude and are easily masked by environmental noise in underwater settings. Consequently, the resulting whisker vibrations are weak and difficult to reliably capture. To address this challenge, we design a spiral-perforated whisker base to enhance sensitivity to fish-generated wakes. The spiral-perforated base amplifies animal wake-induced vibrations by tuning its resonance frequency to match the dominant excitation frequency of the target animal's wake. This resonance-based amplification significantly increases the whisker's vibration response and can be adapted to different target species by adjusting the resonant frequency.

We evaluate the amplification performance of the seal whisker-inspired sensor through simulations of whisker–base vibrational amplitude under harmonic water pressure loading. The results show up to a 51-fold increase in root-mean-square displacement at the target sensing location within frequency bands associated with animal-induced wakes, compared with a baseline design. These findings confirm the effectiveness of the vibration amplification provided by the whisker sensor structure.

Speaker



Yuyan Wu

PhD Candidate | Stanford University

MS 101: Engineering Education: New Trends, Opportunities, and Experiences

9:30 AM – 11:30 AM | Location: UMC 247

Chair(s): Rebecca Napolitano; Fernando Moreu; Roya Nasimi; Wesley Reinhart; Shahlaa Al Wakeel

Moderatorss



Rebecca Napolitano

Assistant Professor | Penn State



Wesley Reinhart

Assistant Professor | Pennsylvania State University

ID 44: AI-lympics: a gamified drone programming framework to engage first-generation students in robotics and infrastructure inspection

9:30 AM – 9:50 AM

Author(s): Francesco Gasperini, University of Massachusetts Lowell; Alessandro Sabato, University of Massachusetts Lowell

Engaging first-generation college students in engineering pathways requires educational experiences that are immersive, relatable, and grounded in authentic applications of emerging technologies. This paper presents the design, implementation, and educational outcomes of AI-lympics: human vs. machine drone races, a multifaceted outreach initiative at the University of Massachusetts Lowell that introduces first-generation students to robotics, artificial intelligence, and drone-borne inspection of civil and mechanical infrastructure. Central to the program is an activity in which students first manually fly a small quadcopter through an obstacle course, gaining hands-on experience with UAV control, safety, and mission planning. They then transition to autonomy by programming the drone using Scratch, developing logic sequences that enable the drone to complete the same course automatically, creating a friendly competition between human-piloted and coded flight. To extend the learning experience toward real-world SHM applications, students also engage in introductory Python modules that teach drones to perform simple perception tasks, including gesture following and object identification. These activities directly mirror workflows used in autonomous inspection, digital twin development, and AI-driven sensing. The autonomous drone system showcased in the AI-lympics incorporates onboard sensing, real-time object detection, and navigation algorithms, reinforcing connections between classroom learning and modern engineering practice. Overall, the AI-lympics provides a scalable, gamified model for reducing barriers to entry STEM education for underrepresented groups while fostering skills relevant to next-generation infrastructure assessment and digital twin technologies.

Speaker



Alessandro Sabato

Dr. | University of Massachusetts Lowell

ID 72: Teaching basic mechanics prerequisite courses before applied mechanics for optimal students' mechanics learning outcome

9:50 AM – 10:10 AM

Author(s): Jiliang Li, California Baptist University; Jinyuan Zhai, Minnesota State University Mankato

As applied mechanics course, soil (and/or rock) mechanics is still a MECHANICS course. It is an applied mechanics' course of directly applying and using what students already learned in their prerequisite courses like Statics, Strength of Materials (or Mechanics of Materials with lab) and Fluid Mechanics in previous semesters. Also, Foundation Engineering use heavily and mostly Statics, Strength of Materials knowledge, for example Friction, Force system Resultant, and Strength of Materials' failure theory and Mohr Circles learned in Strength of Materials or Mechanics of Materials lecture and laboratory courses. We believe that teaching of Foundation Engineering, Soil Mechanics are best aligned and optimized after students have mastered and learned prerequisite courses like Fluid Mechanics, Dynamics Strength of Materials and Statics courses. Another major Geotechnical Engineering course of Soil Dynamics taught in many other universities are immediately related and best aligned and optimized with the teaching, learning instruction of a basic dynamics course such as Dynamics or Dynamics and Vibration courses. Therefore, having an applied nature of mechanics, soil mechanics as well as rock mechanics are applying many (ratio) properties from basic mechanics including Statics, Strength of Materials (or Mechanics of Materials with lab), Dynamics and Fluid Mechanics.

Statics concepts and principles of Force system Resultant (Magnitude, Direction, Location), Equivalent Moment, Support Reaction Forces, Frictions find direct applications in shallow and deep foundation and retaining wall analysis and design.

Strength of Materials or Mechanics of Materials courses concepts of Stress, Strain, Mohr Circles, Major and Minor Principal Stress, Initial yield stress concept and Failure Theory are used directly in Soil Mechanics and Foundation Engineering Lateral Earth Pressure and Retaining Wall Applications.

Fluid Mechanics Concepts of Viscosity, Pressure, Bernoulli Equations, Streamline, Flow Lines, Reynold Number, Laminar and Turbulent Flow, Hydrostatics also find direct applications in Soil Mechanics.

Therefore, optimization of basic mechanics prerequisite courses teaching before applied mechanics for optimal students' mechanics learning outcome is necessary and should be mandatorily required in all universities ABET programs. Offering and teaching fluid mechanics after soil mechanics lecture and laboratory instruction may unwittingly result in students learning soil mechanics memory overflow or soil mechanics learning knowledge overflow partly due to fluid mechanics being considered as challenging courses for its much application of Calculus III. Soil mechanics not only use Calculus III but also Partial Differential Equations (PDEs) like Laplace Steady state seepage PDE and parabolic diffusion consolidation PDEs and consolidation laboratory test and its consolidation coefficient, C_v , measurement estimation etc.

Speaker



Jiliang Li

Assistant Professor | CALIFORNIA BAPTIST UNIVERSITY

ID 352: Bridging the Gap: A Framework for Integrating Engineering Data Science into High School Curricula

10:10 AM – 10:30 AM

Author(s): Rebecca Napolitano, penn state; Wesley Reinhart, Penn State; Robert Mayne, Penn State

As data literacy becomes a cornerstone of modern STEM education, there is a pressing need for scalable, "plug-and-play" modules that can be woven into existing high school curricula without significant overhead. This project, facilitated by an NSF grant and a partnership with Penn State's Center for Science and The Schools (CSATS), focuses on the translation of collegiate engineering data science frameworks into accessible, high-school-level materials. The primary objective is to foster high data literacy and career interest among diverse student populations while significantly reducing the technical entry barriers for classroom teachers. The development process relies on an iterative collaboration between university researchers and practicing educators within regional STEM ecosystems. This partnership ensures that the curriculum is grounded in authentic engineering research while remaining navigable within the constraints of secondary education, such as limited IT support and platform accessibility. Through a Research Experience for Teachers (RET) programs, educators are immersed in data-driven engineering environments, enabling them to bring genuine research contexts back to their students. The curriculum emphasizes critical thinking over rote calculation, teaching students to evaluate automated computer outputs skeptically and recognize that their judgment is superior to default computer identification. Broad thematic areas include the distinction between observational studies and designed experiments, the identification of lurking variables, and the visualization of complex statistical paradoxes through interactive Python simulations in Google Colab.

Speaker



Rebecca Napolitano

Assistant Professor | Penn State

ID 392: New Training of Rebar Inspection Using Augmented Reality and Motion Capture Analysis

10:30 AM – 10:50 AM

Author(s): Mahsa Sanei, University of New Mexico; Kira Kampschmidt, Albuquerque Academy High School; Fernando Moreu, University of New Mexico

The adoption of Augmented Reality (AR) technologies in construction requires effective training strategies that accommodate users with diverse backgrounds and experience and levels of technical expertise. This study presents an educational framework for training an AR-based rebar inspection application to participants ranging from high school students and professionals from non-engineering fields to engineers and company executives. The training approach emphasizes intuitive interaction, voice commands, visual feedback, and progressive task completion guide to enable rapid understanding of inspection principles without prior construction experience. Participants were introduced to rebar spacing concepts, AR visualization, and correction workflows through guided demonstrations and hands-on exercises. This study employed a Vicon motion capture system to objectively evaluate learning outcomes and physical interaction of inspector. A traditional manual approach using tape measures and drawings, and an AR-assisted approach using the developed application were tested. Vicon Tracking motion capture data is used to quantify task duration, walking distance, ergonomic posture changes, and cognitive load across user groups. Results showed that users from all professional backgrounds were able to successfully perform rebar inspection tasks using the AR system after training sessions. The findings demonstrate that AR-based inspection tools can be effectively taught to a wide audience and that immersive visualization can lower cognitive and physical barriers associated with conventional construction inspection. This work highlights the educational value of AR for engineering tasks and new technologies as both a training platform and a new technology that improves understanding, efficiency, and safety in engineering practice.

Speaker



Fernando Moreu

Associate Professor | University of New Mexico

ID 480: AI-Enhanced Multi-Media Generation Platform for Engineering Education

10:50 AM – 11:10 AM

Author(s): Yue Cui, National University of Singapore; Bao Chau To, National University of Singapore

Visualization plays a critical role in engineering education by helping students understand abstract mathematical formulations and dynamic system behavior. However, creating high quality and course specific multimedia resources remains time consuming and technically demanding. We present a cloud-based, AI-enhanced platform for automated generation of scientifically accurate multimedia content for engineering education. The platform enables educators to create static images, animations, videos, and interactive widgets directly from natural language prompts or uploaded teaching materials through a fully graphical, web-based interface requiring no programming experience. Through an intuitive graphical interface with drop-down menus and parameter controls, users can freely select functionality, visualization style, visualization libraries, and underlying AI models to match specific teaching objectives. In addition, experienced users with programming backgrounds can directly modify the AI-generated code within the platform to further customize and refine the resulting visualizations. Unlike general purpose generative AI tools, the system is built on code-driven generation and integrates scientific computing and visualization libraries to ensure mathematical rigor and theoretical correctness, while a Retrieval Augmented Generation (RAG) framework leverages curated repositories of scientific visualization code. The platform has been implemented in multiple engineering courses by different lecturers, where it significantly reduced content preparation time and improved student engagement and conceptual understanding, demonstrating strong potential for scalable adoption across engineering and science disciplines.

Speaker



Yue Cui

Lecturer | National University of Singapore

ID 531: Teaching Structural Steel Design Through Multilevel Project-Based Learning

11:10 AM – 11:30 AM

Author(s): Hussein Ali Ahmad, University of New Mexico; Fernando Moreu, University of New Mexico

This paper presents a disruptive teaching approach for introducing students to steel design through experiential and project-based learning that extends beyond traditional course content. The methodology places undergraduate, graduate, and PhD students in a shared learning environment that promotes knowledge exchange, where undergraduates benefit from the technical experience of graduate students, and graduate students develop leadership and mentoring skills. The course emphasizes the practical application of steel design principles through two major design projects completed within a compressed timeframe that also includes quizzes, homework, oral presentations, and a poster competition. A primary focus is placed on the structural design of a storage warehouse in New Mexico, requiring students to design and detail steel structural components, connections, and base plates in accordance with design standards. A second project involves the conceptual and structural design of a pedestrian bridge, reinforcing load path understanding and system-level behavior. Through these projects, students integrate structural behavior, constructability, teamwork, time management, and technical communication. Overall, the proposed approach enhances technical competency in steel design, leadership development, and collaborative learning, while preparing students to address real-world structural engineering challenges.

Speaker



Bhumika Joshi

Project Assistant | University of New Mexico

MS 084: Recent Advances in Hybrid Simulation and Real-time Hybrid Simulation

9:30 AM – 11:30 AM | Location: UMC 415-417

Chair(s): Wei Song; Richard Christenson; Amirali Najafi

Moderatorss



Wei Song



Richard Christenson

Professor | University of Connecticut

ID 387: Actuator Swivel Friction Compensation Method for Multi-Axial Hybrid Simulation

9:30 AM – 9:50 AM

Author(s): Yoon Jae Kim, University of Toronto; Oh-Sung Kwon, University of Toronto; Chin-Cheng Lin, National Cheng Kung University; Chung-Chan Hung, National Cheng Kung University

Hybrid simulation has been widely applied to a range of structural systems to evaluate system-level structural performance. This testing approach provides a practical alternative to conventional experimental methods, such as quasi-static or shake-table tests, by physically testing only the critical components while representing the remainder of the system through numerical modeling.

In multi-axial hybrid simulations, the displacement of a control point is imposed using multiple actuators to reproduce realistic multi-degree-of-freedom (MDOF) boundary conditions. A practical challenge in such simulations is friction in actuator swivels, which are typically spherical bearings or cylindrical joints installed at both ends of the actuators to accommodate rotation. Swivel friction has been reported in numerous experimental and hybrid simulation studies and is generally considered non-negligible. Its presence can lead to numerical instability or inaccurate force measurements during hybrid simulation, potentially compromising the accuracy of the results.

To address this issue, this study proposes a generalized and systematic framework for compensating actuator swivel friction in MDOF hybrid simulations. The framework corrects friction-induced errors in transforming measured actuator forces into specimen restoring forces. First, swivel friction is modeled using the Dahl friction model. Second, the rotation angles of the swivels are computed at each time step based on the initial coordinates of the actuator ends and the control point. Third, the friction torque at each actuator swivel is evaluated as a function of the rotation angle and actuator force using the friction model. Finally, the friction-induced force at the control point is determined through a Jacobian matrix that maps swivel friction torques to equivalent forces. This friction-induced force is then subtracted from the measured force to obtain an accurate estimate of the specimen restoring force.

The proposed framework is implemented in NICON (Network Interface Program for Controllers), the hybrid simulation controller interface developed at the University of Toronto. Numerical and experimental case studies verify the framework, demonstrating improved force accuracy and enhanced numerical stability in multi-axial MDOF hybrid simulations.

Speaker



Yoon Jae Kim

PhD Candidate | University of Toronto

ID 138: A Multi-Axial Real-Time Aerodynamics Hybrid Simulation Platform for Tall Buildings

9:50 AM – 10:10 AM

Author(s): Santiago Ruiz, University of Alabama; Wei Song, University of Alabama

The construction of tall buildings has accelerated rapidly in recent decades due to urban population growth and increasing land values in metropolitan areas. Wind-structure interaction generates complex aerodynamic forces that produce coupled multi-axial structural responses in tall buildings. Such responses can lead to occupant discomfort, fatigue damage in structural and nonstructural components, and reduced building functionality. Conventional wind tunnel testing methods either fail to capture motion-induced aerodynamic effects or become time-consuming and impractical when attempting to reproduce complex dynamic system behavior. To overcome these limitations, Real-Time Hybrid Simulation (RTHS) has emerged as a promising approach for investigating wind-structure interaction by combining numerical and physical substructures in real-time. RTHS enables complex dynamic components to be captured while a physical building model is tested under a realistic wind environment. Although previous studies have demonstrated the feasibility of RTHS for wind-induced response simulation, they have primarily focused on single-direction excitation, neglecting the inherently multi-axial nature of wind loading on tall buildings. This study proposes a Real-Time Aerodynamics Hybrid Simulation (RTAHS) platform capable of accurately reproducing multi-axial wind-induced responses in tall buildings using a specimen tested in an open-boundary wind tunnel, while enabling the evaluation of multiple RTHS compensation strategies. Extensive experimental testing demonstrates strong agreement between RTAHS and conventional aeroelastic responses and captures complex wind-induced vibrations across multiple cases, highlighting the capability of the proposed RTAHS to realistically simulate multi-directional aerodynamic effects in tall buildings.

Speaker



Wei Song

ID 172: Development of a Real-Time Hybrid Simulation Framework for Floating Offshore Structures in a Wind Tunnel Environment

10:10 AM – 10:30 AM

Author(s): Giheon You, Seoul National University; Minyeop Kim, Seoul National University; Yunbyeong Chae, Seoul National University

Floating offshore structures are subjected to complex environmental loadings, specifically the simultaneous interaction of significant waves and wind. Consequently, accurately evaluating their dynamic response under these combined effects is critical for ensuring structural safety.

While numerical models are widely used to predict these responses, relying solely on simulations introduces uncertainty, making experimental validation crucial. However, conducting physical experiments that account for both environmental factors is challenging due to the difficulty of constructing integrated facilities combining a precise wave basin with a wind tunnel.

To address these limitations, this study proposes a Real-Time Hybrid Simulation (RTHS) framework conducted within a wind tunnel. This methodology involves measuring aerodynamic loads on a scaled model while simultaneously calculating the floating body's displacement using a numerical model. The numerical substructure employs an equation of motion based on potential theory, integrated with nonlinear fluid forces—including viscous drag and second-order wave loads—and a mooring dynamics model. The calculated 6-DOF displacement is physically imposed on the experimental model using a 6-DOF actuating system.

To ensure high fidelity, the Adaptive Time Series (ATS) compensator is employed to enhance actuator control accuracy. Additionally, an inertia compensation algorithm eliminates the inertial forces and weight of the experimental mass from load cell readings, isolating pure aerodynamic loads for the numerical solver. This hybrid loop operates iteratively at a 2ms time step.

The study successfully demonstrated the feasibility of performing RTHS for floating structures in a wind tunnel, confirming the stability of the hybrid loop. Future research will focus on validating results against aerodynamic models and evaluating coupled wind-wave responses for various floating structures.

Speaker



Giheon You

Ph.D. Student | Seoul National University

ID 173: Phase-Minimized Adaptive Filtering Framework for Real-Time Hybrid Simulations

10:30 AM – 10:50 AM

Author(s): Minyeop Kim, Seoul National University; Yunbyeong Chae, Seoul National University

Accurate enforcement of boundary conditions between numerical and experimental substructures is a fundamental requirement in real-time hybrid simulation (RTHS), as it directly governs the stability and accuracy of the experiment. Achieving such accuracy relies on precise actuator control, which in turn depends on the reliable real-time acquisition of sensor measurements. In practice, however, these measurements are inevitably contaminated by noise arising from sensors, actuation hardware, and other physical components of the experimental setup. When such noise propagates through closed-loop control systems—particularly in cases where signal differentiation is required—it can significantly degrade control performance, reduce stability margins, and ultimately lead to divergence of the experiment. Consequently, effective noise mitigation is an essential prerequisite for conducting a stable and accurate experiment. Conventional causal filtering and differentiation techniques mitigate noise at the cost of introducing phase delay, which is highly unfavorable for RTHS applications. Although model-based approaches such as Kalman filtering can reduce delay through predictive estimation, their effectiveness depends strongly on accurate prior knowledge of the system dynamics and noise statistics. This requirement is rarely satisfied in real-time hybrid testing environments, which are often characterized by nonlinear behavior, unmodeled dynamics, and time-varying system properties.

This work proposes a Phase-Minimized Adaptive (PMA) filtering framework for real-time signal processing that mitigates measurement noise while preserving near-zero phase distortion. The PMA filtering approach is model-free, causal, and operates online by formulating real-time filtering as an adaptive identification problem for a locally optimal transfer function. This formulation enables explicit shaping of the magnitude response while directly regulating the effective phase behavior within the passband. By embedding phase alignment into the adaptation process, PMA filter overcomes the fundamental trade-off between noise attenuation and delay that constrains conventional causal filtering and differentiation techniques. Beyond low-pass filtering, the proposed approach naturally extends to causal differentiation, enabling reliable estimation of higher-order signal derivatives required for real-time control without violating strict timing constraints. Moreover, its general structure readily supports extension to other filtering configurations, including band-pass and notch filters for resonance suppression, making the PMA framework a practical and flexible solution for RTHS environments operating under strict real-time requirements.

Speaker



Minyeop Kim

Ph.D Student | Seoul National University

ID 268: Hydrodynamic Real-Time Hybrid Simulation of Deep-Water Mooring Systems subject to Extreme Wave Loading

10:50 AM – 11:10 AM

Author(s): Elaine Liu, Stanford University; Abilyn McConnell, Oregon State University; Yun Ni, Stanford University; Bret Bosma, Oregon State University; Bryson Robertson, Oregon State University; Barbara Simpson, Stanford University

Offshore wave energy has gained significant interest as a clean energy source, with wave energy converter (WEC) development expanding to deeper waters for enhanced wave predictability and higher extractable power output. In deep water regimes, WECs are subject to a multitude of extreme wave loading phenomena, such as from steep, breaking, or near-breaking waves, which can induce impulsive slamming forces and high-frequency dynamic oscillations of devices. These phenomena are typically studied through experimental testing, but traditional wave basins or flumes lack the sufficient depth needed to test devices along with the full-length of deep-water mooring lines at a reasonable scale. Thus, accurate estimation of structural behavior under extreme wave loading remains a significant challenge, motivating the need for alternative testing methods.

Herein, a real-time hybrid simulation (RTHS) is implemented to enable enhanced testing of deep-water devices and their mooring lines. RTHS is a numerical-physical simulation approach that partitions a prototype system into numerical and physical sub-assemblies, which interact through sensors and actuators. The combined numerical-physical sub-assemblies are coupled through the governing equations of motion to represent the complete prototype system. In this implementation, a floating WEC subject to steep wave loading is studied in the Large Wave Flume at Oregon State University. A motor applies forces via an actuation cable onto the WEC to represent contributions from a numerically simulated mooring line extending to greater depths. Sensors on the WEC then measure positional information to update the next iterative state of the numerical mooring line model in real-time.

Results from the RTHS experiment are compared against a full-scale numerical model of the prototype WEC and mooring line to evaluate the extent that the deep-water mooring system can be replicated in a laboratory setting. Discrepancies between the results are used to identify regimes where simplified linear assumptions in the numerical models lose validity, particularly during highly nonlinear wave loading. The effects of limited actuation and potential errors that arise due to inaccurate mooring force application are also discussed.

The implemented RTHS framework virtually extends the depth of the wave flume by simulating the mooring system numerically in real-time, enhancing existing laboratory capabilities. Future work will involve additional comparisons with high-fidelity computational methods, such as Smooth Particle Hydrodynamics (SPH), to characterize discrepancies between experiments and higher-fidelity models.

Speaker



Elaine Liu

ID 319: Numerical Investigation of Control–Table–Specimen Dynamic Interaction for NHERI-UCSD 6-DOF Large High-Performance Outdoor Shake Table

11:10 AM – 11:30 AM

Author(s): Chin-Ta Lai, National Taiwan University; Joel P. Conte, University of California San Diego

The six-degree-of-freedom UC San Diego Large High-Performance Outdoor Shake Table (LHPOST6) was upgraded from its original single-degree-of-freedom configuration between August 2021 and February 2022, and was re-commissioned on June 30, 2022. During the upgrade, a series of acceptance tests were carried out to verify the performance of the upgraded system and to validate a comprehensive multi-physics dynamic model of LHPOST6. Following the installation of steel cover plates for hydraulic-actuator protection, characterization tests were subsequently conducted to identify the fundamental physical properties of the LHPOST6 system and to calibrate the parameters of the corresponding numerical model.

The multi-physics dynamic model of LHPOST6 under bare-table conditions, implemented in Matlab/Simulink, provides a valuable framework for investigating shake table system dynamics and for validating system parameters, including hydraulic properties, frictions, and the effective inertia of mechanical components. Nevertheless, because the shake table is seldom operated in a bare-table configuration, it is essential to examine the system behavior under loaded conditions. A comprehensive investigation of LHPOST6 with mounted specimens is therefore required to bridge the gap between reduced-scale experiments and full-scale shake-table testing. Such an effort necessitates a pre-validated, nonlinear, mechanics-based numerical model of LHPOST6 coupled with a numerical model of the test specimen capable of capturing its nonlinear response.

The closed-loop LHPOST6 system under loaded-table conditions consists of three principal components and their interactions: the motion controller (MTS 469D), the mechanical and hydraulic subsystems of the shake table (LHPOST6), and the specimen mounted on the platen. The specimen–table interaction is characterized by the platen accelerations driving the specimen response and, in turn, by the specimen base shear forces and overturning moments acting on the platen. To represent this coupled behavior, the dynamic models of the shake table and the specimen are implemented in separate software environments, as reprogramming the entire numerical procedure within a single platform would require substantial and uncertain effort. The Open System for Earthquake Engineering Simulation (OpenSees) is adopted to model the test specimens because of its open-source architecture and extensible framework. The communication protocols and interface parameters among the MTS controller, Simulink, and OpenSees are investigated, and the numerical coupling techniques required for integrated simulation framework are developed.

A convergence study is first conducted for the numerical simulation of LHPOST6 under both bare-table conditions and loaded-table conditions with a small virtual specimen, in order to determine the optimal analysis time steps for Simulink and OpenSees. Subsequently, a series of rigid and flexible numerical specimens are employed to validate the LHPOST6 numerical model under different loading scenarios. In parallel, various explicit and implicit numerical schemes are evaluated within the mechanics-based LHPOST6 framework. These simulations are used to quantify the degree of dynamic interaction, assess the accuracy of the coupled numerical model, and examine the fidelity with which the physical closed-loop LHPOST6 system is replicated under loaded-table conditions.

Speaker



Chin-Ta Lai

Prof. | National Taiwan University

MS 096: Coupled Multi-Physics Mechanics of Geomaterials for Energy and Environmental Applications

9:30 AM – 11:30 AM | Location: UMC 382-384-386

Chair(s): Angelica Tuttolomondo; Anne-Catherine Dieudonné

**Anne-Catherine Dieudonné**

Associate Professor Multiphysics Geomechanics | Delft University of Technology

ID 54: Coupled Thermo–Hydro–Mechanical Modeling of Heating and Hydration Processes in Bentonite: Application to a Laboratory Benchmark Experiment

9:30 AM – 9:50 AM

Author(s): Guanlong Guo, Lawrence Berkeley National Lab; Liange Zheng, Lawrence Berkeley National Lab

Bentonite is widely considered a key buffer material in deep geological repositories for high-level radioactive waste owing to its low permeability, strong swelling capacity, and high retention ability for radionuclides. In repository conditions, the bentonite buffer is simultaneously subjected to thermal loading from heat-emitting waste and hydration induced by groundwater inflow from the surrounding host rock. These processes trigger strongly coupled thermo–hydro–mechanical (THM) responses, including vapor transport, liquid flow, swelling and shrinkage, and microstructure-controlled deformation.

In this study, a coupled THM model is developed within the TOUGH–FLAC framework to simulate the heating and hydration behavior of bentonite under controlled laboratory conditions. A temperature-dependent water retention formulation is incorporated to represent the thermally induced changes in moisture retention and relative humidity. The Barcelona Expansive Model is implemented in FLAC3D to explicitly account for the interaction between microstructural and macrostructural deformation during wetting and thermal loading. The proposed model is applied to a laboratory benchmark experiment involving coupled heating and hydration of bentonite.

The simulation results demonstrate that the model captures the observed evolution of temperature, relative humidity, and porosity with good agreement. The study highlights the importance of coupled THM processes and microstructure-informed constitutive modeling for the accurate prediction of bentonite behavior. The developed modeling approach provides a robust numerical tool for the interpretation of laboratory experiments and for performance assessment of engineered barrier systems in radioactive waste repositories.

Speaker**Guanlong Guo**

Postdoc | Lawrence Berkeley National Lab

ID 118: Acidic Environment Enhances Hydro-Shearing in Carbonate Reservoirs

9:50 AM – 10:10 AM

Author(s): Sihan Zhou, The University of Hong Kong; Jing Chen, The University of Hong Kong; Manolis Veveakis, Duke University; Manman Hu, The University of Hong Kong

In contrast to the conventional hydraulic stimulation, which generates a large tensile fracture with secondary fractures distributed nearby, shear stimulation emerges in recent years as a less intrusive technique. Hydro-shearing aims to create an inter-connected fracture network around the injection hole, consisting of generation and re-activation of shear cracks. As demonstrated by field tests, hydro-shearing owns the advantages of effectiveness, low fluid pressure required, and much less micro-earthquake events induced. For low-permeability carbonate-rich reservoirs in deep formations, acidizing treatment is often incorporated to induce chemical softening of the host rock facilitating fluid flow pathways via generation of crack networks. Yet, how rocks respond to the fluid pressurization by injection, particularly the underlying mechanisms governing shear band initiation, development and network forming around the injection borehole - in a chemically reactive environment - remain elusive. Here we present a study on shear-banding in ductile rock formations induced by a combined action of chemical and mechanical loading, from a fundamental perspective of material bifurcation. Benchmarked against analytical solutions and validated with laboratory experiments, our two-way coupled reactive chemo-mechanical model based on Perzyna's formulation demonstrates its capacity of illustrating the shear bands growing from the borehole in the form of logarithmic spirals. The effects of fluid pressurization rate and intrinsic material heterogeneity, respectively, on the dynamic interplay between damage-enhanced dissolution and chemically influenced damage evolution in the rock matrix, are investigated. Our results show that the formation of a potential shear fracture network around a borehole is embedded in the physics of shear instability under internal pressurization, and an acidic environment promotes its triggering.

Speaker**Sihan ZHOU**

MISS | The University of Hong Kong

ID 169: An Analytical Model for Consolidation in Unsaturated Two-Layer Soils

10:10 AM – 10:30 AM

Author(s): Nan-Chieh Chao, National Cheng Kung University; WeiCheng Lo, National Cheng Kung University; Ronaldo Borja, Stanford University

This study develops analytical solutions for consolidation in an unsaturated two-layer soil system subjected to a time-invariant surface stress. Within the framework of unsaturated poroelasticity, the governing equations are formulated to describe the coupled behavior of the solid skeleton, pore air, and pore water phases. The model captures the evolution of excess pore air pressure, excess pore water pressure, and the associated time-dependent total settlement of the soil system. Continuity of pore pressures and fluid fluxes is imposed at the interface between the two soil layers to ensure consistency of the coupled hydro-mechanical processes.

The governing equations consist of coupled partial differential equations describing the interactions between the solid deformation and the pore-fluid pressures in partially saturated soils. To facilitate analytical treatment, appropriate normal-coordinate transformations are introduced to decouple the system into independent modes. The transformed equations are subsequently treated using Laplace transformation in time and Fourier expansion in space. Through this procedure, the boundary-value problem is reduced to a set of ordinary differential equations that admit closed-form solutions.

The resulting analytical framework provides explicit expressions describing the spatial and temporal evolution of pore pressures and total settlement within each soil layer. The solutions establish a theoretical basis for investigating consolidation behavior in layered unsaturated soils and provide a useful benchmark for verifying numerical models developed for coupled hydro-mechanical processes in partially saturated porous media.

Speaker



Nan-Chieh Chao

Dr. | National Cheng Kung University

ID 178: Experimental investigation of the behaviour of a shallow energy wall in a PCM-improved ground

10:30 AM – 10:50 AM

Author(s): Maria Romana Alvi, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino; Alessandra Insana, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino; Marco Barla, Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino

Energy geostructures represent an innovative type of earth-contact structures capable of simultaneously fulfilling structural and energy-related functions by integrating load-bearing elements with the exploitation of shallow geothermal energy. By avoiding dedicated drilling operations, these systems facilitate the deployment of renewable energy solutions in dense urban environments. Despite their potential, the widespread application of energy geostructures for heating and cooling applications and underground thermal energy storage is still limited by several challenges. In particular, installations at shallow depths are strongly affected by seasonal temperature fluctuations, while the close proximity of more geothermal systems in urban settings may lead to thermal interferences, resulting in progressive efficiency losses.

To address these issues, a prototype of a shallow energy wall, named Geothermskin, has been developed at the Politecnico di Torino to investigate underground heat exchange and storage through energy geostructures. The prototype includes six thermally activated geothermal modules grouped in pairs to obtain three independent experimental fields separated by thermal insulating panels, to prevent the occurrence of thermal interactions between adjacent systems.

In one of the three experimental fields, phase change materials (PCMs) were distributed into the soil layers facing the energy wall with the objective of enhancing the heat storage capacity and thermal inertia of the geomaterial. By exploiting latent heat storage, the geomaterial mixed with PCM is expected to mitigate the temperature fluctuations induced by heat extraction and to reduce thermal depletion of the ground reservoir to maintain the efficiency of the shallow geothermal system. An experimental campaign is currently underway, which includes both daytime heat extraction and nighttime underground heat storage operations.

This contribution presents the results of some selected tests from the ongoing experimental campaign carried out to understand the role of PCM on the thermal performance of the energy wall and its impact on the heat transfer process in the ground. The preliminary findings provide insights into the role of PCM-enhanced geomaterials in coupled thermo-hydraulic processes relevant to energy geotechnics and highlight the potential of the integration of PCM as a strategy to improve the thermal performance of energy geostructure and the ground for energy applications.

Speaker



Maria Romana Alvi

STUDENT | POLITECNICO DI TORINO

ID 242: From Geomaterials to Energy Storage: Clay-Based Electrodes for Supercapacitors

10:50 AM – 11:10 AM

Author(s): Xiaohui Gong, Subsurface Opportunities and Innovations Lab, Department of Civil and Environmental Engineering, Northwestern University; Alessandro F Rotta Loria, Subsurface Opportunities and Innovations Lab, Department of Civil and Environmental Engineering, Northwestern University

The rapid expansion of renewable energy technologies, including wind and solar power, is reshaping modern energy systems and accelerating the transition toward low-carbon electricity generation. However, the intrinsic intermittency and strong power fluctuations associated with these renewable sources induce fundamental challenges to grid stability and energy management. Efficient energy storage technologies that are available for buffering short-term power variations and responding rapidly to transient loads are therefore essential for the reliable operation of renewable energy systems. Supercapacitors have been promising candidates to address these challenges due to their high-power density, fast charge and discharge kinetics, and long cycle life. Unlike batteries, which are optimized for high energy density and long-duration storage, supercapacitors are particularly suited for rapid power regulation and transient energy buffering. Despite these advantages, the large-scale deployment of supercapacitors remains constrained by material cost, sustainability, and scalability, motivating the exploration of alternative electrodes from both material and manufacturing perspectives. Clays are a type of geomaterial with properties that are potentially advantageous for electrochemical energy storage: they are naturally abundant, inexpensive, and environmentally friendly. Besides, their negatively charged surfaces, layered structures, and nanoscale interparticle porosity are set to facilitate ion transport and charge storage. However, clays have rarely been investigated as an active electrode material for supercapacitors. This limited exploration is primarily because of their low electronic conductivity and the tendency of clay particles to stack together, hindering ion transport. In this study, a symmetric supercapacitor that applies clays as active electrode materials is investigated. The process of preparing clay electrodes does not rely on complex chemical modification or high-temperature treatment. The resulting system meets the standards (i.e., energy density and power density) of a supercapacitor. This system also exhibits stable electrochemical behavior over repeated charge–discharge cycles, indicating that clay can be a material used for energy storage. By presenting the functional role of clay in supercapacitors, this investigation shows geomaterials as a potential and sustainable candidate for electrochemical energy storage. This study also provides a new insight into ion storage mechanisms in layered natural materials and suggests a way to scalable, low-cost energy storage devices suited for renewable energy systems.

Speaker



Xiaohui Gong

Ms. | Northwestern University

ID 311: Modeling EGS Hydraulic Stimulations as Fluid-Induced Tensile and Shear Fractures

11:10 AM – 11:30 AM

Author(s): Sylvain Brisson, EPFL; Brice Lecampion, EPFL

We investigate two hydraulic stimulation stages performed in April 2022 at the Utah FORGE enhanced geothermal system test site using analytical and numerical models for tensile hydraulic fractures and fluid-induced dilatant shear fractures. The two injection stages differ primarily by the viscosity of the fracturing fluid: low-viscosity slick-water for the first stage and high-viscosity cross-linked gel for the second. Despite similar injection rate schedules and well-head pressure responses, the two stages exhibit markedly different post–shut-in microseismic behavior. The cross-linked gel stage shows sustained microseismic activity for several hours after shut-in, whereas the slickwater stage exhibits an immediate decrease. For the cross-linked gel stage, the located microseismic events benefit from excellent seismic acquisition coverage. They reveal the development of a planar radial fracture and allow confident retrieval of the fracture extent evolution. We demonstrate that this evolution follows the scalings predicted by viscosity–storage–dominated radial hydraulic fracture analytical models, both during injection and post–shut-in, providing strong evidence for the development of a planar tensile hydraulic fracture. We further show that leak-off is required to reproduce the final fracture extent. In contrast, the immediate arrest observed during the slick-water stage suggests either a transition to a toughness- or leak-off–dominated hydraulic fracture regime, or the development of a fluid-induced shear fracture. Using scalings from analytical models of fluid-induced shear rupture, we show that the slickwater stage could plausibly correspond to a dilatant shear fracture, provided sufficient dilatancy, whereas this hypothesis is invalidated for the cross-linked gel stage. We confirm these insights, derived from analytical models, using a 3D axisymmetric fully-coupled hydro-mechanical numerical model capable of resolving both tensile and shear failure modes, and including leak-off. Finally, we propagate uncertainties in the in-situ stress state and natural fracture orientations through this numerical model to assess their impact on injection pressures.

Speaker



Sylvain Brisson

Phd student | EPFL

MS 098: Meshfree, Peridynamic, and Particle Methods: Advancements and Applications

9:30 AM – 11:30 AM | Location: HUMN 1B80

Chair(s): Sheng-Wei Chi; Jiun-Shyan (JS) Chen; Mike Hillman; Pablo Seleson; Tsung-Hui (Alex) Huang; Kuan-Chung Lin

Moderators



Edouard Yreux

R&D Engineering, Architect | Synopsys

ID 671: Extreme Event FSI: A Consistent Volumetric Meshfree Framework for Blast and Fragmentation

9:30 AM – 9:50 AM

Author(s): Michael Hillman, Karagozian and Case, Inc.; Yuri Bazilevs, Brown; Jiarui Wang, SUSTech; Joseph Magallanes, Karagozian and Case, Inc.; Jeff Limbacher, Karagozian and Case, Inc.; Dominic Wilmes, Karagozian and Case, Inc.

Fluid-structure interaction (FSI) in extreme event simulation presents significant computational challenges, primarily because maintaining quality body-fitting meshes during complex fragmentation is often intractable. Specifically, scenarios such as air-blast and perforation generate numerous irregularly shaped bodies undergoing extreme deformations. While immersed and handshake surface-traction methods offer a potential solution by discretizing bodies independently, they typically rely on explicit interface parameterization and element erosion, which leads to non-physical mass loss and questionable definitions of surfaces.

In this work, we develop an immersed volumetric meshfree framework to circumvent the difficulties associated with erosion and traditional immersed and surface-type traction methods [1,2]. The solver, coupling codes, and implementation details are described. This approach utilizes Nitsche and penalty techniques to enforce volumetric continuity between the solid and fluid domains. We demonstrate that the proposed weak forms are fully consistent with the strong form of the multi-body problem in the steady case. The formulation permits C0 approximations for the foreground discretization and C1 approximations for the background, allowing for instance, IGA and FEM as well. The power and robustness of this methodology are demonstrated through complex FSI benchmarks involving the fracture and fragmentation of ductile and brittle solids.

REFERENCES

1. Wang, J., Zhou, G., Hillman, M., Madra, A., Bazilevs, Y., Du, J., & Su, K. (2021). Consistent immersed volumetric Nitsche methods for composite analysis. *Computer Methods in Applied Mechanics and Engineering*, 385, 114042.
2. Behzadiniasab, M., Hillman, M., & Bazilevs, Y. (2021). IGA-PD penalty-based coupling for immersed air-blast fluid–structure interaction: a simple and effective solution for fracture and fragmentation. *Journal of Mechanics*, 37, 680-692.

Speaker



Michael Hillman

K&C

ID 733: Variational Integrators, Least Action, and Neural Network Enriched RKPM

9:50 AM – 10:10 AM

Author(s): Samuel Casebolt, University of California, San Diego; Yanran Wang, University of California, San Diego; J. S. Chen, University of California, San Diego

Conventional numerical methods for dynamic problems can be computationally intensive when addressing localized features where local adaptive refinement is needed. Local adaptive refinement is tedious in meeting the regularity requirements, and the analytical enrichment functions to capture local features are often unavailable. These complexities become even more pronounced in transient problems. This work introduces a neural network-enriched Reproducing Kernel Particle Method (NN-RKPM) for solving dynamic problems based on action minimization under a symplectic space-time framework. In this approach, RKPM is employed in the background spatial discretization and approximation, and the background solution is adaptively enriched with neural network basis functions. The neural network enrichment functions are pre-trained during the offline stage to learn specific local features through Ritz-type energy minimization, with the addition of a proper orthogonality constraints applied to ensure the optimization enriches the local strain solution. With NN-RKPM, the dynamic problem is also solved as an optimization problem, with the time domain interpolation to assemble and discretize the NN enriched action functional. The evolution of the background RKPM and NN enriched time-dependent solution is driven by principles of least action through symplecticity preserving variational integration algorithms derived from first principles.

The proposed method presented offers a unified framework consistent with the classical field theory, variational integrators, and has been shown to accurately capture the time-dependent response of mechanical systems. This application of mechanics and machine learning is then examined for computational efficiency and solution accuracy through the examination of several local feature specific elastodynamics test cases.

Speaker



Samuel Casebolt

Graduate Student | University of California, San Diego

ID 753: Generalized Nodal Integration with Non-Confirming Cells for Galerkin Methods

10:10 AM – 10:30 AM

Author(s): Sheng-Wei Chi, University of Illinois Chicago; Mohammed M. Atif, Synopsys

Domain integration remains a major bottleneck in Galerkin-based numerical methods, particularly when advanced approximations such as meshfree methods, generalized partition of unity methods, and convolution-based finite element methods are employed. Stabilized conforming nodal integration (SCNI) introduces smoothed gradients over conforming nodal subdomains to recover Galerkin exactness and establishes the concept of integration constraint [1]. Subsequently, the variationally consistent integration method generalized this idea by satisfying integration constraints through appropriate modifications of the test functions [2]. Motivated by these developments, a generalized gradient-smoothed nodal integration is introduced, based on non-confirming nodal subdomains for gradient smoothing [3], thereby distinguishing it from the SCNI. The proposed method achieves linear exactness without non-confirming cells and, under certain conditions, quadratic exactness without additional computational cost. Convergence properties for partial differential equations with various boundary conditions are analyzed and verified through numerical examples. Furthermore, the proposed nodal integration scheme is extended to the displacement-pressure formulation for porous media. Benchmark problems are presented to demonstrate the accuracy, robustness, and computational advantages of the proposed approach.

1. JS Chen, CT Wu, S Yoon, Y You, "A stabilized conforming nodal integration for Galerkin mesh-free methods," International Journal for Numerical Methods in Engineering 50 (2), 435-466, 2001.
2. JS Chen, M Hillman, M Rüter, "An arbitrary order variationally consistent integration for Galerkin meshfree methods," International Journal for Numerical Methods in Engineering 95 (5), 387-418, 2013.
3. Liheng Fan, Like Deng, Dongdong Wang, "A node-based consistent non-conforming gradient smoothing scheme for highly efficient Galerkin meshfree formulation," Engineering with Computers 41:1555–1573, 2025.

Speaker



Sheng-Wei Chi

Associate Professor | University of Illinois Chicago

ID 847: DualSPHysics-INL: a critical state soil mechanics based Smoothed Particle Hydrodynamics solver for granular flow

10:30 AM – 10:50 AM

Author(s): Yumeng Zhao, University of Nebraska - Lincoln; Wencheng Jin, Texas A&M University; Lumanti Shakya, University of Nebraska - Lincoln

The simulation of granular materials under large deformation, such as landslides of geomaterials and the processing of biomass feedstocks in handling equipment, presents significant computational challenges due to their complex constitutive behavior and high deformation. With the increasing popularity of using Smoothed Particle Hydrodynamics (SPH) to tackle the large deformation of fluid and granular matter, we introduce DualSPHysics-INL, a GPU-accelerated advanced SPH solver developed as an extended adaptation of the DualSPHysics open-source framework (v5.0.1).

The primary contribution of DualSPHysics-INL is the integration of a Gudehus & Bauer hypoplastic constitutive model based on critical state soil mechanics. This implementation enables the simulation of a broad spectrum of granular mechanical responses, capturing pressure- and density-dependent behavior essential for geotechnical and industrial applications. To ensure numerical stability during high-energy interactions, the solver utilizes a momentum-based boundary condition. This approach effectively prevents particle penetration under fast material-boundary interaction while facilitating a full range of frictional interfaces, from free-slip to frictional and no-slip conditions.

We demonstrate the solver's capabilities through a series of validation cases, including biomass handling and soil deformation, highlighting its robustness in predicting flow patterns and reaction forces on boundaries. We also show that due to the inherent discretization with a volumetric kernel function, SPH provides a weak non-local behavior that traditional mesh-based methods are not able to achieve without sophisticated inclusion of non-local behavior: Shear band width in numerical simulation shows less mesh size dependence, and SPH is able to realize clogging that traditional methods cannot. Although further improvements are needed, this shows more potential for SPH in simulating real-world granular flow problems that are large in deformation, with shear rates spanning low to high regimes, and non-local behavior. DualSPHysics-INL provides a powerful, high-performance tool for researchers and engineers tackling the unique mechanical challenges of granular media in the energy and civil engineering sectors. We would like to introduce this solver to the granular mechanics community.

Speaker



Yumeng Zhao

U Nebraska Lincoln

ID L1: Extended Finite Element Method for Buckling Analysis of Folded Plate Structures

10:50 AM – 11:10 AM

Plates and folded structures are fundamental in engineering, yet high-precision stability analysis via the Finite Element Method (FEM) often requires computationally expensive fine meshes. This study presents a computationally efficient approach for the linearized buckling analysis of folded-plate structures using the eXtended Finite Element Method (XFEM).

Unlike traditional XFEM targeting local discontinuities, this method employs a global enrichment strategy to enhance the approximation space across the entire domain. The framework integrates analytical Navier series [1] and author-developed in-plane functions [2] into a hierarchical enrichment scheme. By embedding these analytical features into a standard coarse FE mesh, the formulation significantly reduces the total degrees of freedom required for convergence without sacrificing spectral accuracy.

To capture complex deformation modes, the model utilizes a general Kirchhoff formulation—incorporating both in-plane and out-of-plane terms of the nonlinear Green–Lagrange strain tensor. This offers a robust alternative to the commonly adopted von Kármán approach, particularly in scenarios where membrane-bending coupling significantly influences the onset of instability [3].

A series of case studies on thin-walled plates and complex folded structures are presented. The results demonstrate that the enriched formulation yields a substantially higher convergence rate and a marked reduction in computational effort compared to standard FEM, maintaining accuracy even across diverse boundary conditions.

References

- [1] A. Zisimos, A. Marzok, and H. Waisman, "Efficient xfem/gfem approach for the analysis of thick plates utilizing global enrichments," *International Journal for Numerical Methods in Engineering*, vol. 7010, no. 10, pp. 1–18, 2025.
- [2] A. Zisimos, A. Marzok, and H. Waisman, "Xfem approach for folded plate structures with global enrichment functions," *Thin-Wall. Struct.*, 2025.
- [3] A. Zisimos, A. Marzok, and H. Waisman, "Extended Finite Element Method for Buckling Analysis of Folded Plate Structures," *Eng. Struct.*, 2026.

Speaker



Athanasios Zisimos

Dr. | Columbia University

ID 569: Performance-Portable Implementation of a Meshfree Method for Computational Mechanics

11:10 AM – 11:30 AM

Author(s): Jake Koester, Aperi CMC; Kurtis Ford, Aperi CMC

Meshfree methods offer significant advantages for challenging problems in computational mechanics, including robust handling of large deformations and material failure. However, efficient implementation of these methods on modern heterogeneous computing architectures presents substantial challenges due to their reliance on neighbor searches and point-based approximations that differ fundamentally from traditional finite element approaches. This talk presents a performance-portable implementation strategy for meshfree methods that achieves efficient execution across CPUs and GPUs while maintaining a single, maintainable codebase.

We demonstrate this approach using the Conforming Reproducing Kernel (CRK) method^{1,2}, which combines the flexibility of Reproducing Kernel approximations with mesh-based information for boundary conditions and integration domains. CRK provides an ideal testbed for performance portability studies due to its computational intensity and the complexity of its shape function construction, which involves neighbor searches, moment matrix assembly, and matrix inversions at each integration point.

The implementation, realized in our *aperi-mech* code, leverages the Kokkos programming model for performance portability and the Sandia Toolkit (STK) for mesh data structures. This architecture enables parallel execution via MPI for distributed memory, threading for shared memory, and GPU acceleration—all from a unified source code. We present performance results demonstrating significant speedups on GPU architectures compared to CPU execution, with particular attention to the strategies employed to efficiently map meshfree computations to GPU hardware.

Beyond the core performance-portable framework, we discuss recent extensions for modeling material damage and failure, illustrating the method's applicability to complex engineering problems involving fracture and fragmentation. These capabilities highlight how a well-designed performance-portable foundation enables rapid development of advanced physics capabilities while maintaining computational efficiency across diverse hardware platforms.

1. Koester, Jacob J., and Jiun-Shyan Chen. "Conforming Window Functions for Meshfree Methods." *Computer Methods in Applied Mechanics and Engineering* 347 (2019): 588–621. <https://doi.org/10.1016/j.cma.2018.12.042>.

2. Koester, Jacob J., Michael Tupek, and Scott Mitchell. "An Agile Design-to-Simulation Workflow Using a New Conforming Moving Least Squares Method." Sandia National Laboratories, 2019.

Speaker



Jake Koester

CTO | Aperi CMC

MS 095: Characterization and modeling of physical and chemical processes in porous materials across scales

9:30 AM – 11:30 AM | Location: VAC 1B20

Chair(s): Mostafa Mobasher; Pania Newell; Sara Abedi; Manolis Vevakis; Jean-Michel Pereira; Giuseppe Buscarnera; Yanni Chen; Ghassan Shahin; Rigoberto Moncada

Moderatorss



Rigoberto Moncada Lopez

LLNL



Mostafa Mobasher

Assistant Professor | New York University Abu Dhabi

ID 67: Exploring the Potential of Mechanically Weakened Peridotites for Enhancing and Sustaining Carbon Mineralization

9:30 AM – 9:50 AM

Author(s): Hoang Nguyen, Los Alamos National Lab; Wenfeng Li, Los Alamos National Lab; Chelsea Neil, Los Alamos National Lab; Austin Selley, Los Alamos National Lab; Cate Tilley, Los Alamos National Lab; Michael Pettes, Los Alamos National Lab; Luke Frash, Los Alamos National Lab; Hari Viswanathan, Los Alamos National Lab

Large-scale CO₂ removal relies on an integrated application of carbon capture, utilization, and storage (CCUS) technologies, including geological storage, chemical conversion, and mineralization. Among these, carbon mineralization is particularly promising, offering a permanent pathway for CO₂ sequestration. Ultramafic rocks, such as peridotites, are especially well suited for this process due to their high olivine content and rapid carbon fixation potential. However, their intrinsically low porosity and permeability restrict fluid injectivity and limit reaction efficiency, posing major challenges for large-scale implementation. In the first part of this study, we address the permeability constraint by targeting naturally fractured and weathered peridotite zones, as well as experimentally induced fracture networks [1]. By incorporating triaxial direct-shear (TDS) fixtures into core-flooding experiments and coupling them with X-ray microtomography, weathered dunite samples collected from the Twin Sisters Range (WA) and Jackson County (NC) demonstrated sustained fluid flow and, consequently, enhanced carbonation reactions. Notably, the self-propping effect of in situ induced fractures helped maintain high permeability over extended operational periods, with minimal sensitivity to confining pressures up to 32 MPa. The second part of this study focuses on addressing critical knowledge gaps in carbonation performance within these permeable veins—specifically, the influence of fluid type (aqueous versus wet supercritical CO₂), CO₂ concentration, and pore and confining pressures on mineral dissolution and secondary (and tertiary) mineral precipitation. To investigate these effects, we analyzed pre- and post-reaction samples using scanning electron microscopy (SEM), Raman spectroscopy, energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), and X-ray fluorescence (XRF). Results indicate that Mg–Fe stoichiometry, rather than olivine content, governs the reaction rate, while the composition of the aqueous CO₂ injectant dictates whether dissolution or precipitation dominates. Although supercritical CO₂ yielded reaction rates comparable to those of aqueous CO₂ under the same pore pressure, the formation of iron–silicate layers inhibited subsequent dissolution and precipitation. These findings provide critical insights into the physicochemical controls on peridotite carbonation and offer practical guidance for optimizing depth, fluid chemistry, and pore pressure conditions to enhance CO₂ mineral trapping efficiency.

1. Neil, Chelsea, et al. "Experimental investigation of coupled geochemical-geomechanical processes during carbon mineralization in fractured mafic and ultramafic rocks." AGU24 (2024).

Speaker



Hoang Nguyen

Postdoc | Los Alamos National Lab

ID 68: Modeling of non-coaxial deformation in sands: Roles of fabric anisotropy and non-proportional loading

9:50 AM – 10:10 AM

Author(s): Lei Huang, Zhejiang University; China; Zhongxuan Yang, Zhejiang University; China; Yannis F. Dafalias, University of California, Davis; United States

Experimental investigations have demonstrated that granular soils can exhibit non-coaxial deformation, whereby the principal directions of stress and plastic strain rate do not coincide. This behavior originates primarily from two mechanisms: inherent fabric anisotropy and non-proportional loading paths, such as stress principal axes rotation (SPAR). Such responses deviate from the coaxial assumptions inherent in classical plasticity theory and have therefore become a central issue in the constitutive modeling of soils. In this study, a bounding surface model, termed SANISAND-FZ, is developed to describe non-coaxial soil behavior. Building on its immediate predecessor SANISAND-Z, the model adopts a zero purely elastic range, such that the yield surface collapses to the current stress point. Within the framework of anisotropic critical state theory and by incorporating a fabric-based modified stress, the model consistently captures the influence of fabric anisotropy on stiffness, dilatancy, and plastic flow. With the adopted stress-rate mapping rule, plastic loading can be activated for any stress ratio rate direction, with both the loading and the plastic strain-rate directions depending on that direction. On this basis, non-coaxial deformation under non-proportional loading is further reproduced through appropriate modifications to the constitutive expressions. This is achieved without introducing additional plastic loading mechanisms or piecewise formulations commonly employed in traditional approaches. The capability of the proposed model to simulate non-coaxial behavior is validated through comparisons with experimental results from both proportional and non-proportional loading tests under drained and undrained conditions.

Speaker



Lei Huang

PhD student | Zhejiang University

ID 148: Mechanistic Modeling of CO₂-Driven Stress Corrosion Cracking and Degradation in Quartz-Rich Shale Rocks

10:10 AM – 10:30 AM

Author(s): Shaziya Ahmed Banu, Texas A&M University; Sara Abedi, Texas A&M University

A semi-analytical modelling framework is developed herein to simulate the reactive damage progression in quartz-rich shale rocks induced by stress corrosion cracking under elevated temperature and pressure conditions. Although quartz is typically considered to be a mechanically robust and chemically stable mineral, exposure to concurrent effects of mechanical loading and a corrosive environment can result in stress corrosion cracking, leading to localized degradation, compromised mechanical stability, and the formation and propagation of microcracks. Collectively, these processes contribute to the mechanical degradation of shale, thereby impacting the long-term formation integrity, energy recovery performance, and containment reliability. Hence, this study presents a semi-analytical approach to simulate and predict the mechanical degradation of quartz-rich shale due to stress corrosion cracking on exposure to CO₂-saturated brine at high temperature and pressure conditions. The proposed model mechanistically links geochemical reactions to subcritical fracture kinetics in shale by relating bond rupture processes to crack growth rates. Leveraging nanoindentation data obtained from the unreacted shale rocks, the model predicts the spatiotemporal evolution of porosity, local stress intensity factor, crack length per unit area and crack density, along with the mechanically degraded properties resulting from CO₂ saturated brine exposure at 100°C and 1800 psi. The results indicate a substantial reduction in the elastic modulus along with a higher crack density localized near the reacted surface of the quartz-rich phase. The trends agree closely with the experimental observations, confirming the model's reliability and accuracy. Overall, this study delivers key insights by (1) presenting an efficient predictive framework for mechanical degradation of quartz-rich shale under reactive conditions and (2) clarifying the mechanisms underlying CO₂-induced fracture behavior in these materials. Furthermore, the proposed model offers a cost- and time-efficient alternative to experimentation of heterogeneous rock specimens, facilitating enhanced evaluation of mechanical deterioration of subsurface formations in the context of carbon storage and energy systems.

Speaker



Shaziya Ahmed Banu

Ph.D. Student | Texas A&M University, College Station, TX 77840

ID 331: A Chemo-poromechanical Model Coupled with Reactive Transport of Mineral Reactions in Subsurface Geologic Systems

10:30 AM – 10:50 AM

Author(s): Fan Fei, Lawrence Livermore National Laboratory; Yifan Yang, Northwestern University; Giuseppe Buscarnera, Northwestern University; Randolph Settgaest, Lawrence Livermore National Laboratory; Kari Finstad, Lawrence Livermore National Laboratory; Giovanna Bucci, Lawrence Livermore National Laboratory; Alex Zibitsker, Lawrence Livermore National Laboratory

Geochemical processes involving mineral precipitation and dissolution are ubiquitous in subsurface geologic systems, where they play a key role in controlling coupled behavior relevant to geothermal systems, carbon storage, and critical mineral extraction. Accurate numerical modeling of the chemo-hydro-mechanical processes is essential for predicting and analyzing the evolution of rock permeability, porosity, and the stress condition, thereby enabling optimized engineering operations and risk management. Prior efforts to incorporate the feedback of mineral reactions on the geomechanics include the eigen-strain approach and empirical or semi-empirical phenomenological methods. These approaches, however, suffer from several intrinsic limitations and, most importantly, fail to account for the poromechanical nature of the rock. To address this gap, we adopt a poromechanics-based analytical framework recently proposed by Yang and Buscarnera (2025) to capture internal mechanical interactions induced by mineral precipitation or dissolution. The framework has been simplified by assuming isotropic behavior and is implemented in the open-source multiphysics simulator GEOS, where the mechanics solver is sequentially coupled with the single-phase reactive transport module. The numerical model is subsequently applied to examples representative of an ultramafic geologic system, and the results are compared with those obtained using the previous eigen-strain approach to demonstrate the model's capabilities and unique feature. Further extensions integrating certain fracture modeling technique will also be discussed and presented to showcase the broader applicability of the proposed model.

Yang, Y., & Buscarnera, G. (2025). A Poromechanical Framework for Internal Interactions Induced by Solid Inclusions. *International Journal for Numerical and Analytical Methods in Geomechanics*, 49(7), 1804-1819.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Speaker



Alex Zibitsker

Postdoctoral Researcher | Lawrence Livermore National Laboratory

ID 760: Disorder-induced flow localization in permeable matrix-inclusion morphologies

10:50 AM – 11:10 AM

Author(s): Amirmahdi Rabiee, Sonny Astani Department of Civil and Environmental Engineering, University of Southern California; Thomas Petersen, Sonny Astani Department of Civil and Environmental Engineering, Department of Aerospace and Mechanical Engineering, University of Southern California

Fluid transport through soft, heterogeneous porous media is inherently coupled to deformation of the solid skeleton, leading to complex feedback between flow pathways, internal stresses, and microstructural disorder. Such behavior is central to a wide range of biological, geological, and engineered materials, including tissue, wood, soils, and polymeric membranes. In this work, we present a poromechanical network model that captures the coupled mechanics of fluid flow and elastic deformation in two-dimensional disordered microporous media composed of rigid inclusions embedded in a compliant, permeable matrix phase.

The microstructure is generated using a Monte Carlo algorithm to produce controlled degrees of disorder at fixed inclusion volume fraction. The resulting morphology is mapped onto a dual network representation: an elastic solid network of nodes connected by stretching and bending springs, and a pore network that governs fluid transport through the interconnected void space. The two- and three-body interactions of the solid network allow the model to accurately capture stress distributions generated from volumetric and deviatoric deformation.

The stiffnesses of the network elements are calibrated using micromechanical homogenization based on Mori–Tanaka theory, ensuring that the effective bulk and shear moduli of the ordered reference configuration match those of the underlying matrix–inclusion composite. This calibration enables a quantitative link between local network mechanics, inclusion volume fraction, and material contrast. Fluid flow through the pore network induces local pressures and capillary stresses that act on the solid network, driving deformation of the matrix and displacement of the inclusions, which in turn modifies pore geometry and flow pathways.

The proposed framework is designed to investigate how internal stresses generated by fluid invasion may enhance or suppress preferential flow channels as a function of microstructural disorder and elastic contrast. By explicitly resolving disorder-induced non-affine deformation of the solid network and its feedback on pore geometry, the model enables systematic study of the stress redistribution and the evolution of transport pathways in deformable porous media. This approach highlights the role of microstructural morphology in governing coupled fluid–solid interactions and provides a flexible foundation for future studies aimed at designing porous materials with tailored mechanical and transport properties.

Speaker



Amir Rabiee

USC

ID 221: Thermodynamically Consistent Modelling of Chemically Enhanced Grain Crushing in Reactive Porous Media

11:10 AM – 11:30 AM

Author(s): Chuangao Chen, Research Centre of Coastal and Urban Geotechnical Engineering, College of Civil Engineering and Architecture, Zhejiang University; Yanni Chen, Research Centre of Coastal and Urban Geotechnical Engineering, College of Civil Engineering and Architecture, Zhejiang University

In geotechnical systems, such as tailings dams, nuclear waste repositories, and carbon sequestration sites, the presence of chemically active pore fluids could dissolve the solid skeleton which might degrade the fracture toughness, promote grain crushing microscopically and alter the mechanical behaviors macroscopically due to the promoted subcritical crack growth. This study extends the breakage mechanics to chemically reactive porous media and develops a thermodynamically consistent modelling framework to measure the influence of solid dissolution on the performance of geomaterials. At the particle scale, the model links the evolution of surface energy with the adsorption and reaction kinetics of the involved ionic species to quantify the chemically promoted subcritical crack propagation. The formulation naturally recovers the Gibbs adsorption isotherm which connects the fracture toughness to the chemical potential. At the scale of granular assembly, the coupling between the chemical and mechanical process is incorporated in the energy storage function through a simplified microscopic idealization which correlates the microstructure evolution with the chemical kinetics. The model is validated against experimental measurements at both scales which show good performance. The results also stress the importance to incorporate proper physicochemical mechanisms when understand and predict the mechanical behavior of porous media under complex chemical environments which would scientifically assist the engineering applications of deep-ground energy extraction and storage.

Speaker



Chuangao Chen

College of Civil Engineering and Architecture, Zhejiang University

Lunch Break

11:30 AM – 1:00 PM

Lunch tent #1

11:30 AM – 1:00 PM

Lunch tent #2

11:30 AM – 1:00 PM

Keynote: Redefining the Computation-Mechanics Nexus in Large-Scale 6-DOF Shake-Table Testing

1:00 PM – 2:00 PM | Location: UMC - Glenn Miller Ballroom

Redefining the Computation-Mechanics Nexus in Large-Scale 6-DOF Shake-Table Testing

Joel P. Conte, Ph.D., P.E., F. EMI, F. ASCE

Distinguished Professor Eric and Johanna Reissner Endowed Chair

Department of Structural Engineering

University of California, San Diego

Abstract: The UC San Diego Large High-Performance Outdoor Shake Table (LHPOST) was commissioned on October 1, 2004, as a shared-use facility under the U.S. National Science Foundation (NSF) Network for Earthquake Engineering Simulation (NEES) program. Although originally conceived as a six-degree-of-freedom system, budget constraints led to its initial construction as a single-degree-of-freedom table. After 15 years of operation, it was upgraded to its intended 6-DOF capabilities between October 2019 and April 2022 and renamed LHPOST6.

A multi-physics model (digital twin) of the LHPOST6 was developed. Under bare-table conditions, the model integrates three subsystems: (1) hydraulic dynamics, (2) pneumatic (nitrogen-precharged) hold-down struts, and (3) three-dimensional kinematics and dynamics of the mechanical components, including the platen and actuators. A methodology was established to calibrate model parameters and validate the model using acceptance and characterization test data.

For loaded-table conditions, a coupled dynamic model was developed by integrating: (a) the MTS 469D table motion controller, (b) the LHPOST6 model in Simulink, and (c) nonlinear structural specimen models in OpenSees. A numerical solution algorithm was formulated for the resulting nonlinear equations of motion. The model was validated against two full-scale experiments: the 10-story mass timber building tested in the NHERI TallWood project and the 6-story mass timber building tested in the NHERI Converging Design project. We explored the long-standing, powerful concept of model-based controller tuning to improve ground motion tracking using a numerical model of the shake table-specimen-controller system, thereby reducing the risk of damaging high-value test specimens during tuning.

The presentation will highlight and discuss key aspects of the model, its validation, and potential applications in large-scale shake table testing.

Biosketch: Joel Conte received his Civil Engineering Diploma in 1985 from the Swiss Federal Institute of Technology in Lausanne, Switzerland, and his M.S. (1986) and Ph.D. (1990) in Civil Engineering from the University of California, Berkeley. He is currently a Distinguished Professor of Structural Engineering at the University of California, San Diego, where he holds the Eric and Johanna Reissner Chair in Applied Mechanics and Structural Engineering. Before joining UC San Diego in 2001, he served on the faculty at Rice University (1990–1997) and UCLA (1998–2001). He is a Fellow of the ASCE Engineering Mechanics Institute (class of 2018) and a Fellow of ASCE (class of 2025). He is also a Fulbright scholar (class of 2006).

Professor Conte's primary research interests include structural modeling and analysis; earthquake engineering and structural dynamics; random vibrations; structural reliability and risk analysis; probabilistic performance-based analysis and design; shake table dynamics and control; experimental-analytical correlation studies; structural identification; Bayesian inference and calibration of mechanics-based structural models; and structural health monitoring. He has published over 300 papers in international journals and conference proceedings.

Professor Conte was a member of the design team for the Large High-Performance Outdoor Shake Table (LHPOST) at UC San Diego, developed as part of the NSF George E. Brown Network for Earthquake Engineering Simulation (NEES). He served as Principal Investigator for the NSF-funded project to upgrade the LHPOST to six degrees of freedom (2018–2022) and was Director of the UC San Diego Englekirk Structural Engineering Center (2011–2023), which houses the NSF Natural Hazards Engineering Research Infrastructure (NHERI) LHPOST6 shake table experimental facility.

Speaker



Joel Conte

Distinguished Professor | University of California, San Diego

Moderators



Mija Hubler

Associate Professor | University of Colorado Boulder

MS 071: 5th Mini-Symposium on civil infrastructure in a changing climate: from nonstationary risk assessment to developing adaptation strategies

2:15 PM – 3:35 PM | Location: HUMN 250

Chair(s): Eun Jeong Cha; Abdollah Shafieezadeh; Michele Barbato; Alexandros Taflanidis

Moderatorss



Michele Barbato

Professor | University of California, Davis



Mohamed Abdelhafez

Postdoctoral Researcher | Vanderbilt University

ID 511: Evaluating extreme ice loads in the United States Using Downscaled CMIP6 Climate Data

2:15 PM – 2:35 PM

Author(s): Mengting Chen, State University of New York Polytechnic Institute; Ahmed Abdelaal, State University of New York Polytechnic Institute; Mari Tye, National Center for Atmospheric Research; Kathy Jones, U.S. Army Corps of Engineers; Rachel McCrary, National Center for Atmospheric Research; Lee Kessenich, National Center for Atmospheric Research; Bimal Yadav, State University of New York Polytechnic Institute

Ice accreting from freezing rain poses critical hazards to civil infrastructure systems, including transmission and distribution lines, communication towers, bridges, and other exposed structural components. Ice accreting on structures significantly increases gravity loads and the concurrent wind load has been responsible for widespread infrastructure damage, cascade failures of power lines, and prolonged service disruptions. Ice thickness is therefore a key engineering design consideration in the construction of many structures exposed to the weather.

Current engineering practice relies on location-specific extreme ice thicknesses, such as those provided by the ASCE Atmospheric Ice Geodatabase and accessed through the ASCE 7 Hazard Tool. These values are primarily derived from historical observations at weather stations. However, substantial uncertainty remains in estimating ice thicknesses between weather stations, particularly in mountainous regions where these stations are sparse and complex terrain influences both the type of precipitation and wind speed. Moreover, existing design values are based on historical weather conditions and may not adequately represent future icing risks under a changing climate.

To address these limitations, this study employs dynamically downscaled weather data from climate models to estimate ice thicknesses across the United States. The data have a spatial resolution of approximately 12 km and an hourly temporal resolution, driven by several Earth system models from the CMIP6 multi-model ensemble. Extreme ice thicknesses are evaluated for four structural Risk Categories, consistent with engineering design standards, using historical simulations during the period from 1950 to 2014. Projected future ice thicknesses are assessed under a future climate corresponding to a 3 °C global warming level (3GWL) relative to preindustrial by 2100, in order to quantify potential changes in icing risk associated with global warming. This study identifies regions vulnerable to increasing freezing rain loads under changing climate conditions. The ultimate goal is to support resilient infrastructure design for a sustainable future.

Speaker



Mengting Chen

Postdoctoral | State University of New York Polytechnic Institute

ID 817: An extended performance-based hurricane engineering framework including climate change and structural aging effects

2:35 PM – 2:55 PM

Author(s): Lei Zhou, University of California, Davis; Michele Barbato, University of California, Davis

Climate change is modifying environmental conditions through sea level rise, increasing temperatures, and shifting precipitation patterns, which contribute to hurricanes that are more intense and occur more frequently. Concurrently, structural aging (i.e., the gradual deterioration that occurs over a building's service life) can significantly diminish structural performance. These effects can be intensified by climate change due to extreme weather events, elevated humidity, and additional environmental stressors.

This study extends the Performance-Based Hurricane Engineering (PBHE) framework by incorporating two critical aspects: climate change–driven variations in hurricane hazards and aging-related changes in structural vulnerability. The primary goals are to develop an enhanced PBHE framework that accounts for nonstationarity in both hazards and vulnerability and to demonstrate its application through a representative case-study structure.

A steel frame building located in Miami, Florida, and subjected to wind loading is used as a reference model considering a 50-year service life. The influence of climate change is modeled using projected wind speeds derived from sea surface temperature data reported in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. Structural aging is modeled considering two phenomena: (1) the reduction over time in the structure's initial strength due to steel corrosion, and (2) the effects of cumulative damage due to multiple extreme events over the service life of the building. Structural aging introduces statistical correlation between the structural performance of the given building at different times, highlighting the importance of introducing two different time scales (i.e., the global time scale to describe the effects of climate change, and the structural time scale to describe the structural aging phenomenon) in the extended PBHE methodology.

The results underscore the compounded effects of climate change and structural aging on building performance and highlight the importance of resilient design approaches. Ultimately, the findings are intended to inform the development of structures that are more robust and adaptable to future climate-related risks.

Speaker



Lei Zhou

PhD candidate | UC Davis

ID 884: Evaluating the effectiveness of adaptation strategy for reducing long-term hurricane impacts on residential buildings in coastal communities

2:55 PM – 3:15 PM

Author(s): Jiatae Li, Colorado State University; John van de Lindt, Colorado State University

Coastal communities are facing escalating risks from hurricane-induced hazards in a changing climate. This study evaluates the effectiveness of adaptation strategies in reducing long-term hurricane impacts on coastal communities, with a particular emphasis on population stability. To address the deep uncertainty associated with future climate change, this work adopts a scenario-based framework in which representative climate change scenarios are defined in terms of specified levels of sea surface temperature rise and their corresponding sea level rise projections. Based on these scenarios, adaptation strategies that achieve different levels of resilience are systematically evaluated and compiled into a Climate Adaptation Matrix (CAM). The CAM provides a clear and intuitive representations of expected adaptation outcomes across climate change scenarios, allowing stakeholders and policymakers to readily compare strategies and simplifying decision-making under uncertainty.

Long-term community resilience in this study is primarily quantified using cumulative population outmigration, which represents permanent displacement of the population resulting from hurricane impacts over the planning period. Unlike temporary population displacement or dislocation, outmigration takes into account the influence of prolonged recovery processes on individuals' decisions to leave high-risk regions. As such, cumulative outmigration is a suitable indicator for assessing the long-term social impacts and community resilience associated with repeated hurricane events.

To reduce cumulative population outmigration, this study analyzes two approaches for an adaptation strategy. The engineering-based method involves hurricane retrofitting to enhance building wind resistance and building elevation to accommodate intensifying water-related hazards. This approach is optimized through a building selection process, in which specific buildings are prioritized for early implementation within the planning period to maximize long-term resilience benefits. The other approach involves property acquisition strategies, which are constrained by program budgets. In this case, cost allocation is optimized to minimize long-term social impacts. Miami Beach, Florida, is used as an illustrative example. Tailored CAMs are developed to compare the effectiveness of different adaptation strategies in reducing long-term hurricane-induced social impacts, highlighting trade-offs across climate change scenarios.

Speaker



Jiatae Li

Student | Colorado State University

ID 623: Durable Carbon-Negative Enzymatic Structural Materials

3:15 PM – 3:35 PM

Author(s): Pardis Pourhaji, Worcester Polytechnic Institute; Dalton Vassallo, Worcester Polytechnic Institute; Suzanne Scarlata, Worcester Polytechnic Institute; Nima Rahbar, Worcester Polytechnic Institute

The production of conventional structural materials is energy-intensive and responsible for significant carbon dioxide emissions, motivating the development of alternative low-carbon construction technologies. In this work, we introduce a durable, high-strength, carbon-negative enzymatic structural material (ESM) fabricated using a capillary suspension technique. The material integrates enzymatically precipitated calcium carbonate crystals within a sand-hydrochar matrix through enzyme-catalyzed mineralization, enabling rapid solidification and molding into structural components within hours, thereby eliminating the 28-day curing period associated with traditional concrete. The resulting ESM exhibits water stability and an average compressive strength of 25.8 MPa, exceeding the minimum requirement for structural concrete applications. Life-cycle assessments indicate that ESM production sequesters approximately 6.1 kg CO₂ per cubic meter, in contrast to the ~330 kg CO₂ per cubic meter emitted during conventional concrete production. The combination of mechanical performance, environmental sustainability, and rapid fabrication highlights the potential of ESM as a viable carbon-negative alternative for structural building applications.

Speaker



Nima Rahbar

White Family Distinguished Professor | Worcester Polytechnic Institute

MS 012: Objective Resilience: Advancing Multi-Hazard Physical-Socio-Economic Community Resilience using Physics- and AI-based Modeling and Digital Technologies

2:15 PM – 3:35 PM | Location: HUMN 135

Chair(s): Omar Nofal; Milad Roohi; Yousef Darestani; Lisa Wang

Moderators



Milad Roohi

Assistant Professor | University of Nebraska-Lincoln

ID 301: Mitigation of Cascading Failures in Overhead Power Distribution Systems from Wind-induced Loads and Windthrown Fallen Trees

2:15 PM – 2:35 PM

Author(s): Amir Tajik, Michigan Technological University; Yousef Darestani, Michigan Technological University; Scott Holmes, Resilient Structures; Shawn Van Hoek-Patterson, Resilient Structures

In the United States, power distribution systems are primarily supported by wood poles. Aging of wood is a major challenge for power systems, particularly in coastal settings where exposure conditions are harsh. Experience has shown that during strong wind events, aged poles are more prone to failure, which can trigger a domino effect (cascading failures) where adjacent poles fail in quick succession due to load redistribution.

The literature on the reliability analysis of utility poles often treats poles as individual components, without considering interactions among adjacent poles. In this process, the wind-induced loads are estimated based only on the pole itself and the conductors it carries. However, when a single pole fails, load redistribution and the dynamic behavior can significantly increase the load demand on adjacent poles, leading to cascading failures. In addition, in many urban settings, taller trees are often located near distribution lines. During strong wind events, these trees frequently fail. The momentum of a falling tree is transferred to the conductors and can cause conductor failure or overload of the poles, which may lead to cascading failures.

To reduce the risk of cascading failures, utility companies often specify stronger composite poles intermittently along the distribution line. These stronger poles are often referred to as anti-cascade poles. Existing studies often neglect the dynamic interaction between wind-thrown trees and distribution lines, and therefore, they only perform a static analysis.

This study proposes an improved framework for analysis and for mitigating cascading failures in power distribution systems subjected to strong winds and wind-thrown trees. To achieve this goal, the dynamic interactions between fallen trees and distribution lines, as well as between falling poles and adjacent poles, are first modeled using Finite Element Analysis in ANSYS LS-Dyna. This approach simulates the transient dynamic shock caused by the impact of a wind-thrown tree, and the redistribution of unbalanced loads between failed poles and adjacent poles. Second, a sequential Monte Carlo simulation is developed that successively redistributes loads to adjacent poles. The successive failure realizations are estimated using redistribution of loads combined with Bernoulli trials.

The framework is applied to a segment of a hypothetical distribution system with 100 poles arranged in a straight line. The distribution system is subjected to a 3-sec gust wind speed that can vary between 80 to 200 mph. The analysis estimates cascade failures for the following cases: a) the distribution line is supported by 45 ft, Class 1, 50 year old, wood poles; b) the distribution line is supported by 45 ft, Class 1, new wood poles; c) the distribution system is primarily supported by 45 ft, Class 1, new wood poles but is strengthened every 3rd, 5th, or 10th pole by anti-cascade Class 1-equivalent composite poles.

The results indicate that when the distribution line is not strengthened with anti-cascade poles, most failures are due to cascading effects. However, when anti-cascade composite poles are placed, cascading failures and subsequently the total number of failures are significantly reduced.

Speaker



Amir Tajik

Graduate Research Assistant | Michigan Technological University

ID 482: A Computational Framework for Joint Resilience and Sustainability Assessment of Coastal Power Distribution Systems under Storm Hazard

2:35 PM – 2:55 PM

Author(s): Saeed Sohrabi, Michigan Technological University; Yousef Darestani, Michigan Technological University; William Pringle, Argonne National Laboratory

Coastal power distribution systems are highly vulnerable to storm-induced wind, surge, and wave hazards. This vulnerability primarily stems from failures in aged wood poles resulting in widespread power outages. The literature on reliability and resilience analysis of coastal power distribution systems uses fragility models that are either too generic or inaccurate. Moreover, estimating the functionality of power distribution systems with thousands of poles demands computationally time-consuming network connectivity analyses. Furthermore, the impact of resilience improvement strategies on the environmental dimension of sustainability has not been quantified in the context of power distribution systems.

This study addresses these limitations by first developing a set of high-fidelity parametrized fragility models for wood and prestressed concrete (PC) poles, by training an Artificial Neural Network (ANN) model from Monte Carlo simulations. Second, a precomputing (surrogate) method is used to reduce the computational demand for connectivity-based power system performance analysis. This method pre-calculates outages due to failure of individual poles and then reuses them as many times as needed by merging the power outages for the assembly of failed poles, hence significantly reducing the computational costs by avoiding time consuming graph connectivity analysis. Third, an index is proposed to quantify the environmental sustainability based on Carbon Dioxide (CO₂) emissions associated with manufacturing, transportation, and installation of utility poles. Lastly, the resiliency and environmental dimension of sustainability are integrated through a unified index called Eco-Resiliency (ER) for decision making purposes. The proposed framework is applied to the power distribution system of Pascagoula, MS, consisting of 3,509 utility poles connected to five substations. Various pole replacement strategies, including reactive, proactive, and hybrid scenarios, are applied to the case study power system to evaluate the tradeoffs between resilience and environmental sustainability through ER index. ANN-based fragility models and the precomputing network analysis approach decrease the computational time significantly. Furthermore, the results indicate that the most resilient strategy may not be the most environmentally sustainable. ER is a flexible metric that can be used as an alternative decision-making metric offering a balance between resiliency and environmental sustainability.

Speaker



Saeed Sohrabi

Graduate Student | Michigan Technological University

ID 533: Probabilistic Functional Recovery Assessment of RC Wall Buildings with Force-Limiting Connections

2:55 PM – 3:15 PM

Author(s): Sena Mursel, Lehigh University; Paolo Bocchini, Lehigh University; Georgios Tsampras, University of California San Diego; Carlos Franco Mayorga, University of California San Diego

Post-earthquake building performance is increasingly judged not only by life safety, but by how quickly and reliably a facility can regain functionality. Recent earthquakes have repeatedly shown that buildings can remain structurally stable yet experience prolonged downtime due to nonstructural damage, system outages, and recovery impediments. Force-Limiting Connections (FLCs) have been proposed as a resilience-focused technology to control force transfer and damage concentration, but their influence on functional recovery outcomes and especially on the variability and tail risk of recovery has not been comprehensively quantified within a probabilistic framework.

This study proposes a probabilistic functional recovery assessment framework and applies it to a reinforced-concrete building system with conventional connections and an alternative configuration incorporating force-limiting connections. The framework combines nonlinear time-history structural analyses to capture global response measures under suites of earthquake records across multiple hazard levels with a surrogate mapping that translates global shaking intensity measures and building attributes into the floor-level intensity measures required for component fragility assessment. These demands are then propagated through a PBEE-based recovery engine that simulates component damage, repair actions, sequencing and interdependencies, workforce allocation constraints, and impeding factors. The result is an ensemble of building-level functionality trajectories representing the stochastic evolution of usable occupancy over time. Building performance is evaluated using probability-distribution-aware recovery metrics, including percentile recovery curves, probabilistic functionality curves, downtime exceedance relationships for target functionality thresholds, variability-based measures that capture predictability, and decompositions that attribute delays to administrative impediments versus physical repairs.

Results indicate that FLC-equipped systems exhibit improved functional recovery performance relative to conventional configurations, not only by accelerating typical recovery trajectories but also by narrowing the spread of outcomes and reducing the likelihood of prolonged downtime. The probabilistic metrics reveal differences that are not apparent from mean recovery curves alone, highlighting the importance of characterizing tail behavior and recovery reliability when comparing alternative designs. In addition, downtime decomposition suggests that as physical repair demands are reduced through improved seismic response, non-technical impediments can become dominant constraints on timely recovery. Overall, the proposed framework provides a transparent, decision-oriented basis for evaluating building systems against functional recovery objectives, enabling design comparisons that explicitly account for uncertainty, variability, and recovery bottlenecks. The outcomes of the probabilistic framework discussed in this presentation will inform a practical prescriptive resilience-based design methodology for buildings with force-limiting connections.

Speaker



Sena Mursel

Ms | Lehigh University

ID 591: A Uniform Approach for Prioritizing Facility Resilience Investments: A Case Study on US Naval Academy

3:15 PM – 3:35 PM

Author(s): Sushreyo Misra, Lehigh University; Andrea De Marco, La Sapienza University & University School for Advanced Studies IUSS Pavia; Ming Liu, Naval Facilities Engineering and Expeditionary Warfare Center; Nathan Lemme, Naval Facilities Engineering and Expeditionary Warfare Center; Sarah Mouring, United States Naval Academy; Tori Tomiczek, United States Naval Academy; Paolo Bocchini, Lehigh University

Decision-making on resilience investments is an inherently multi-faceted problem that requires explicit consideration of functional recovery, adaptability, resource availability, and performance objectives across spatially distributed assets and hazard scenarios. For a military installation, multiple infrastructure assets (e.g., buildings, road networks, power and water supply systems) and operational procedures contribute to resilience. The common values of the different forms of resilience (e.g., timeframe and objectives) need to be explicitly stated and quantified, so that prioritizing facility resilience investments can be done in a rational and efficient way. With this overarching goal, this study develops and demonstrates a uniform approach for resilience assessment that enables quantitative evaluation of how alternative investments and policy decisions influence installation-level resilience under external perturbations, with a focus on natural hazards. By applying consistent resilience assessment metrics and decision tools across alternative facility design and evaluation, the proposed approach enables identification of systematic improvements to resilience planning and design requirements, especially in Unified Facilities Criteria (UFCs) for decision-making on Navy facility resilience investments.

The United States Naval Academy (USNA) serves as the testbed for the proposed approach. Chronic, tidally-driven flooding is selected as the hazard, and various hazard intensities are assessed for their effects on buildings, transportation infrastructure, and electric power supply systems. Two computational platforms, INCORE and PRAISys, are evaluated to test their ability to perform community-level resilience assessment and resilience-informed investment prioritization. Flood intensity measures are derived from pre-run SLOSH simulation outputs. The installation (i.e., the USNA campus) damage and functional disruption are modeled using user-defined fragility functions accounting for static inundation, while functional recovery is represented through simplified models. Network-level impacts are quantified using topological performance metrics, including connectivity, total travel time, and network efficiency. A suite of flood mitigation alternatives is then analyzed, and their impacts on system- and region-level resilience are quantitatively compared. The resulting approach is a general-purpose, computational platform, supporting resilience-based flood mitigation planning and enabling adaptation to broader regional resilience studies across infrastructure systems and hazard types.

Speaker



Paolo Bocchini

Professor | Lehigh University

MS 016: Decision-making towards resilience on complex, uncertain, and evolving socio-physical systems

2:15 PM – 3:35 PM | Location: HUMN 125

Chair(s): Raul Rincon; Jamie E. Padgett; Mauricio Sanchez-Silva; Leonardo Duenas- Osorio; Dan M. Frangopol

Moderators



Raul Rincon

Incoming Assistant Professor | University of Colorado Boulder

ID 672: Life-cycle assessments that yield service and safety measures disaggregated by community features

2:15 PM – 2:35 PM

Author(s): Raul Rincon, Rice University; Jamie E. Padgett, Rice University; Mauricio Sanchez-Silva, Universidad de los Andes (Colombia)

Designing policies for the long-term management of infrastructure systems is challenging because interactions among infrastructure systems, the environment (e.g., natural hazards), and social systems (e.g., shifts in population needs) are constantly reshaping. How the infrastructure system, decision-makers, and societies adapt to evolving interactions determines whether the system is fit for purpose or underperforms in the face of upcoming hazardous events. However, underperforming systems are commonly associated with infrastructure that fails to meet operational demands and with operating under unsafe conditions. That is, most of the attention is placed on physical performance without suggesting whether system performance (and its shortfalls) affects economic sectors or subpopulations with different abilities to sort out the deficit. To account for the performance of subpopulations or economic sectors, we propose attributed graph representations and performance formulations that enable us to analyze disaggregated life-cycle costs and benefits by user or sector type. In this study, we use sequential decision analysis to investigate how adaptive decision-making over the system states affects socio-physical performance over time. Instead of monitoring the network's functional capacity or reliability (associated with the physical system), our method observes potential imbalances in affected subpopulations resulting from damage to the physical system. We illustrate the proposed approach using transportation networks exposed to multiple threats (e.g., aging) and hazards (earthquake and hurricane-related loads). By understanding and inferring short- and medium-term changes in socio-physical interactions, we seek to objectively establish whether any infrastructure intervention is needed to mitigate potential disparities. We expect our method to yield service and safety measures — disaggregated by community features — that support the design of effective and equitable management policies, improving adaptive decision-making on socio-physical infrastructure systems.

Speaker



Raul Rincon

Incoming Assistant Professor | University of Colorado Boulder

ID 641: Systems Thinking for Construction Management: Dynamic Decision-Making in Complex Projects

2:35 PM – 2:55 PM

Author(s): Felicia Anderson, University of Cambridge

Construction infrastructure management requires dynamic decision-making to prevent functionality loss during uncertain and evolving conditions. Existing safety management models address stakeholder coordination but cannot provide sufficient evidence of intervention effectiveness to justify implementation costs. Complex Adaptive Systems theory provides a framework for mapping safety risk properties arising from agent interactions rather than predetermined management activities, enabling more meaningful representation for Prevention Through Design interventions where design decisions remain malleable. However, applying CAS modelling to complex construction safety problems has been limited by insufficient integration of empirical stakeholder data with dynamic systems representations.

This research develops a systems-based analytical framework that integrates policy and regulatory process mapping with models of adaptive professional behaviour to examine how safety outcomes emerge across design–construction transitions. By combining STAMP-based mapping of regulatory control structures with CAS-informed analysis of agent interactions, the framework captures interfaces between human, technological, and regulatory factors throughout project phases. This integrated approach provides comprehensive visualization and analysis of how safety performance evolves within the complex, multi-level environment of UK construction, addressing critical challenges in dynamic decision-making for infrastructure management under uncertain and evolving conditions.

The methodology applies to UK construction projects during RIBA stages 0-3 and construction delivery, using empirical data from construction professionals and systematic examination of RIDDOR incident patterns. Through causal loop diagrams and system dynamics modelling, the research identifies feedback loops and non-linear effects where strategic agent additions or removals produce disproportionate safety outcomes across project phases. The framework systematically maps four distinct agent categories: Static Agents (regulatory framework), Dynamic Technology Agents (digital tools), Moving Process Agents (cyclical safety processes), and Dynamic Human Agents organised by project phase, revealing how safety emerges from interactions within complex socio-physical systems.

Industry validation through senior construction professionals grounds theoretical models in practitioner experience, enabling analytical and computational modelling of management decision frameworks. This supports safer, more resilient infrastructure system performance under evolving regulatory conditions (CDM 2015, HASAWA 1974, Building Safety Act 2022), providing predictive capabilities for adaptive management in complex socio-physical systems rather than reactive problem identification, directly addressing the challenges of implementing adaptive management in complex networked systems.

Speaker



Felicia Anderson

PhD Researcher | University of Cambridge

ID 750: Project Prioritization for Near-optimal Functionality Risk Reduction in Bridge Networks

2:55 PM – 3:15 PM

Author(s): Anteneh Deriba, Portland State University; David Yang, Portland State University

The disruption of bridges during extreme events can lead to profound societal consequences, ranging from increased travel costs for road users to the loss of access to critical services. Consequently, transportation agencies are tasked with prioritizing assets and retrofitting projects, often under limited resources. Existing protocols frequently neglect asset interdependency related to critical transportation functionalities, instead adopting asset-centric analyses to rank projects. These methods typically rely on vulnerability-based, direct consequence-based, or single-asset failure impact assessments. Although intuitive and practical, such protocols often yield suboptimal outcomes compared to optimization-based project selection. Conversely, full-scale optimization is computationally challenging and lacks robustness against fluctuating budgetary constraints.

This study presents a risk-informed prioritization method to select and refine projects that effectively mitigate risk under uncertain budget constraints. Notably, network risk based on a specific transportation functionality indicator is assessed only once using the Transitional Markov Chain Monte Carlo (TMCMC) method previously proposed by the authors. The proposed method leverages MCMC byproducts to define disaggregated asset importance measures that capture the contribution of low-likelihood, high-consequence damage states across all assets. These asset-level importance measures are then integrated with existing prioritization protocols, such as benefit-based (risk reduction) or benefit-to-cost ratio rankings. The resulting selection heuristic is benchmarked against (a) ground truths for small-scale networks and (b) common global optimization algorithms for medium- to large-scale applications. Results demonstrate that the new heuristic outperforms asset-centric conventions in risk reduction, particularly when rare events induce network islanding effects.

Speaker



David Yang

Assistant Professor | Portland State University

MS 030: Physics-based data-driven modeling and uncertainty quantification in computational science and engineering

2:15 PM – 3:35 PM | Location: HUMN 1B50

Chair(s): Bahador Bahmani; Ramin Bostanabad; Johann Guilleminot; Michael Shields; Wei Chen; Lori Graham Brady

Moderators



Bahador Bahmani

Assistant Professor | Northwestern University

ID 546: Batch Active Learning with Heteroscedastic Gaussian Processes for Microstructure-Property Prediction

2:15 PM – 2:35 PM

Author(s): Ozge Ozbayram, Johns Hopkins University; Audrey Olivier, University of Southern California; Lori Graham-Brady, Johns Hopkins University

Accelerating materials design requires surrogate models that can learn structure-property relationships from limited data. Active learning can guide efficient exploration of the design space, but materials data often exhibit input-dependent noise and mechanical properties are sensitive to local microstructural features, introducing heteroscedasticity. For an effective framework, both the surrogate model and the active learning strategy should account for this variability.

To address this challenge, we develop a Heteroscedastic Gaussian Process Regression (HGPR) model that explicitly decomposes predictive uncertainty into epistemic and aleatoric components. The epistemic uncertainty, arising from limited training data, is captured through the Gaussian process posterior variance and reducible through strategic sampling. The aleatoric uncertainty, representing inherent variability in the structure-property mapping, is modeled through a polynomial noise function that depends on microstructural inputs. Strategic sampling through active learning can improve mean predictions and aleatoric uncertainty by targeting informative regions across the input space.

Using this model, we compare four acquisition functions under heteroscedastic conditions: Expected Improvement for Global Fit (EIGF), Active Learning Cohn (ALC), Mutual Information (MI), and Fisher Information (FI). While MI and ALC achieve strong performance through balanced exploration, EIGF and FI yield limited spatial coverage. EIGF concentrates on high-noise regions while FI clusters samples for noise refinement. To overcome these limitations and enable parallel simulation runs, we introduce a batch sampling approach that groups candidates by acquisition value using k-means clustering, then selects one sample from each cluster. This enforces diversity among selected points while retaining informative samples.

As a case study, we apply the framework to predict effective stress response from Finite Element simulations of porous microstructures. Starting from 10 initial samples, batch active learning achieves accurate predictions. With the same number of added samples, batch EIGF and FI match the performance of single-query MI through improved spatial coverage. The learned noise model correctly identifies void volume fraction and aspect ratio as primary drivers of response variability, validating HGPR's ability to extract physical insight from limited data.

In summary, the proposed framework combines heteroscedastic surrogate modeling with batch active learning, enabling efficient use of parallel computing resources while achieving competitive performance across acquisition functions in heteroscedastic settings.

Speaker



Ozge Ozbayram

Graduate Student | Johns Hopkins University

ID 593: Beyond Scalar Surrogates: High-Dimensional and Spatially Explicit Reliability Assessment of Transmission Towers via Graph Neural Networks

2:35 PM – 2:55 PM

Author(s): Mazin Al-Mahrouqi, The Ohio State University; Abdollah Shafieezadeh, The Ohio State University; Jieun Hur, The Ohio State University; Jae-Wook Jung, Korea Atomic Energy Research Institute; Jeong-Gon Ha, Korea Atomic Energy Research Institute; Daegi Hahm, Korea Atomic Energy Research Institute

The resilience of electrical power grids against intensifying extreme weather events is contingent upon the structural integrity of transmission towers. Current industry practices for grid vulnerability assessment typically rely on representative fragility curves derived from high-fidelity Finite Element Method (FEM) simulations. While FEM provides the necessary physical rigor, it is computationally prohibitive to apply to every asset within a large-scale network, particularly when analyzing complex nonlinear behaviors. To address this computational bottleneck, the research community has increasingly turned to surrogate modeling. However, conventional data-driven surrogates often map complex structural states into low-dimensional scalar metrics, such as a single factor of safety or failure probability. This approach obscures the underlying failure mechanisms, creating a black box that offers limited insight into spatial location or mode of failure, thereby limiting engineering trust and actionable decision-making.

To overcome these limitations, this study proposes a spatially explicit surrogate modeling framework enabled by Graph Neural Networks (GNNs). Unlike conventional scalar-based models, the proposed framework operates as a high-dimensional predictor capable of generating dense output fields. By mapping the finite element mesh topology directly into a graph representation, the model learns to predict the full-field structural response from basic input parameters. This architecture exploits the non-Euclidean nature of graph convolution to capture long-range dependencies and local interactions within the truss system. This approach leverages the capacity of deep learning to handle high-dimensional outputs to generate complex, spatially resolved results rather than simple labels.

The framework is trained to simultaneously predict full-field nodal deformations and classify discrete element-level damage under varying wind loads. The granularity of the output transforms the utility of the surrogate. In addition to failure probability, the model provides a detailed map of structural behavior, allowing engineers to interpret the predicted failure logic, bridging the gap between computational speed and engineering verifiability. Preliminary results demonstrate that the model accurately predicts the onset of nonlinear buckling behaviors that govern collapse. This spatial explicitness enables a new class of probabilistic risk assessment, allowing for the generation of detailed failure maps that pinpoint specific component vulnerabilities, thereby informing targeted maintenance and hardening strategies.

Speaker



Mazin Al-Mahrouqi

PhD Student | The Ohio State University

ID 611: Quantitative validation methodology for physics-based process-to-structure models in additive manufacturing

2:55 PM – 3:15 PM

Author(s): Arulmurugan Senthilnathan, Vanderbilt University; Pranav Karve, Vanderbilt University; Sankaran Mahadevan, Vanderbilt University

Macro-scale mechanical properties and performance of a material are predicted using multi-scale micromechanical models that require microstructure data. In metal additive manufacturing (AM), the fabrication of coupons and experimentally scanning a microstructure of the coupon using techniques such as Focus Ion Beam (FIB) and Electron Back Scattering Diffraction (EBSD) is expensive and time-consuming. Therefore, the process-to-structure (P-S) computational models are necessary to alleviate the experimental burden. The P-S model predicts the microstructure, given the AM process parameters and material properties, by describing the AM process through governing equations. However, the assumptions and approximations in the governing equations of the P-S model propagate to the predicted microstructure features. Currently, P-S models in metals AM are commonly validated through the following two methods: (i) qualitative method (e.g., visual inspection of microstructures) that does not estimate the accuracy and precision (reliability) of the P-S model, (ii) quantitative method that considers only accuracy in some of the microstructural features. This work presents a quantitative validation method that estimates both accuracy and precision in P-S model-predicted microstructure features using probabilistic metrics. First, the characteristic features (e.g., grain orientation) of the P-S model-predicted and scanned microstructures are quantified using selected descriptors (e.g., quaternions, point-based correlation functions, etc). Probabilistic metrics are then defined to compare the descriptors of predicted and scanned microstructural features. Quantitative model validation methods using probabilistic metrics pave the way for systematic uncertainty aggregation in the property and performance prediction, and support model-assisted qualification and certification of additively manufactured products.

Speaker



Arulmurugan Senthilnathan

University Researcher | Vanderbilt University

ID 651: Streaming Identification of Dynamics via Random Projection-based Weak-SINDy

3:15 PM – 3:35 PM

Author(s): Kyuwon Lee, Ann and H.J. Smead Department of Aerospace Engineering Sciences, University of Colorado Boulder; Alireza Doostan, Ann and H.J. Smead Department of Aerospace Engineering Sciences, University of Colorado Boulder

The Weak-form Sparse Identification of Nonlinear Dynamics (WSINDy) has proven effective in identifying differential equations for high-dimensional dynamical systems. By using weak formulations, WSINDy mitigates the numerical instability associated with derivative estimation and enables robust equation discovery from noisy data in offline settings. However, applying WSINDy to high-dimensional dynamics in a streaming data environment remains challenging due to prohibitive memory and computational costs. This capability is particularly crucial for applications such as real-time control, digital twins, and long-term monitoring, where data is generated continuously and storing the full history of high-fidelity measurements is infeasible. Several attempts have been made to adapt WSINDy to streaming scenarios. One online approach, based on proximal gradient descent, may require maintaining a substantial sliding window of snapshots in memory in order to accurately approximate gradients and weak-form integrals. As the spatial resolution increases, the memory footprint and computational cost of this approach quickly become prohibitive. Another approach utilizes Streaming Proper Orthogonal Decomposition (POD) to reduce dimensionality prior to equation identification. This approach typically necessitates an excessive number of snapshots for initialization and requires storing high-dimensional spatial modes that match the original snapshot resolution. Moreover, despite their computational overhead, neither approach has demonstrated robustness under severe noise conditions. To overcome these limitations, we propose a novel streaming WSINDy algorithm capable of handling high-dimensional, large-noise environments with minimal snapshot requirements. The core idea of our approach involves constructing a compressed weak-form library matrix and time derivative vector by utilizing randomized algorithms. This strategy substantially reduces memory usage and decouples computational cost from spatial resolution, thereby alleviating the curse of dimensionality inherent in high-dimensional data-driven modeling. Numerical experiments on various benchmark partial differential equations including the Kuramoto–Sivashinsky equation, Reaction–Diffusion systems, the Euler–Bernoulli beam equation, and high-dimensional Navier–Stokes flows demonstrate that the proposed method robustly identifies governing equations even under high-noise streaming conditions.

Speaker



Kyuwon Lee

University of Colorado Boulder

MS 032: Advances in Mechanics-Informed Machine Learning for Digital Twins

2:15 PM – 3:35 PM | Location: HUMN 150

Chair(s): Mohamad Alipour; Zixin Wang; Zhidong Zhang; Furkan Lülecı

Moderators



Zixin Wang

Dr. | University of Illinois Urbana-Champaign

ID 198: Physics-Guided Hierarchical Domain Adaptation for Sim-to-Real Radar-Based Subsurface Sensing

2:15 PM – 2:35 PM

Author(s): Zixin Wang, University of Illinois Urbana-Champaign; Ishfaq Aziz, University of Illinois Urbana-Champaign; Mohamad Alipour, University of Illinois Urbana-Champaign

Accurate estimation of subsurface material properties, such as soil moisture, is critical for wildfire risk assessment and precision agriculture. Ground-penetrating radar (GPR) is a non-destructive geophysical technique widely used to characterize subsurface conditions. Data-driven parameter estimation methods typically require large amounts of labeled training data, which is expensive to obtain from real-world GPR scans under diverse subsurface conditions. A physics-based GPR model using the finite-difference time-domain (FDTD) method can be employed to generate large synthetic datasets through simulations across varying material parameters, which are then utilized to train data-driven models. A key limitation, however, is that simulated data (source domain) and real-world data (target domain) often follow different distributions, which can cause data-driven models trained on simulations to underperform in real-world scenarios. To address this challenge, this study proposes a novel physics-guided hierarchical domain adaptation framework with deep adversarial learning for robust subsurface material property estimation from GPR signals. The proposed framework is systematically evaluated through the laboratory tests for single- and two-layer materials, as well as the field tests for single- and two-layer materials, and is benchmarked against state-of-the-art methods, including the one-dimensional convolutional neural network (1D CNN) and domain adversarial neural network (DANN). The results demonstrate that the proposed framework achieves higher correlation coefficients R and lower Bias between the predicted and measured parameter values, along with smaller standard deviations in the estimations, thereby validating their effectiveness in bridging the domain gap between simulated and real-world radar signals and enabling efficient subsurface material property retrieval.

Speaker



Zixin Wang

Dr. | University of Illinois Urbana-Champaign

ID 508: Noise-Robust Deep Learning-powered DIC Surrogate Model for Digital Twin Applications

2:35 PM – 2:55 PM

Author(s): Zhidong Zhang, University of Virginia; Ayatollah Yehia, University of Virginia; Zahra Zhiyanpour, University of Virginia; David Wang, University of Virginia; Devin Harris, University of Virginia

Digital image correlation (DIC) has revolutionized the ability for full-field measurements for surface deformation, providing the capability to describe the mechanical response non-invasively. These capabilities provide a pathway for leveraging DIC within a broader digital twin framework; however, the need for two-way interaction between the digital model (twin) and real-time measurement remains a challenge. This research aims to introduce a noise-robust AI-enabled image-based full-field deformation measurement protocol for infrastructure systems, which can function as a surrogate model for DIC applications. A Convolutional Neural Network (CNN) algorithm was employed to construct the baseline model, which takes one reference image and another image with deformation information embedded as input and outputs corresponding full-field deformation measurements. We completed a series of DIC tensile tests on steel coupons considering various noisy scenarios caused by focus and lighting defects to quantify the noise of collected images in terms of gray value. Additionally, we developed a Power Spectral Density (PSD)-based noise characterization strategy to realize the noise sampling considering both spatial structure and temporal evolution matching the collected noise data. The baseline model was fine-tuned with updated noisy input image datasets, and the results are showing promising robustness of the fine-tuned models. The findings and proposed protocols in this research can expand the possibilities of real-time robust DIC evaluation, advancing digital twin practices, and augmenting human decision-making efficacy.

Speaker



Zhidong Zhang

Postdoctoral Research Associate | University of Virginia

ID 902: A Digital Representation Framework for Interpreting Short Term Monitoring in Bridge Capacity Assessment

2:55 PM – 3:15 PM

Author(s): Mohammadreza Rajaei, University of Illinois Urbana-Champaign; Mohamad Alipour, University of Illinois Urbana-Champaign; Larry A. Fahnestock, University of Illinois Urbana-Champaign

Abstract

Bridge load rating assessments typically rely on prescribed traffic load models and conservative assumptions that may not reflect site-specific conditions. While long-term structural monitoring has been proposed to improve load characterization, most bridges are monitored only for short durations due to practical and economic constraints. The role of short-term monitoring data in bridge rating assessment therefore remains unclear. This study proposes a monitoring-informed framework for incorporating short-term structural response data into site-specific bridge rating assessment. The framework employs a digital representation of bridge behavior to interpret measured responses under actual traffic and to inform capacity-rating parameters while explicitly accounting for the limited duration of monitoring. Rather than replacing established rating procedures, the approach aims to support rating assessment by providing data-informed insight into site-specific load effects and their associated uncertainty. The proposed concept highlights the potential of short-term monitoring to contribute to bridge rating decisions and establishes a foundation for integrating data-driven methods within practical, monitoring-informed assessment workflows.

Keywords: Bridge load rating, Short term monitoring, Digital representation, Uncertainty characterization

Speaker



Mohammadreza Rajaei

Mr | University of Illinois Urbana-Champaign

ID 985: Grounding Foundation Models in Physical Reality through Structural Graph Fusion for Cross-Condition Predictive Maintenance

3:15 PM – 3:35 PM

Author(s): Sizhe Ma, Carnegie Mellon University; Katherine Flanigan, Carnegie Mellon University; Mario Bergés, Carnegie Mellon University

Predictive maintenance (PMx) has become a cornerstone of modern industrial management, and digital twins (DTs) have emerged as a leading solution for enabling it. Beyond real-time monitoring, DTs act as information repositories supporting a broad set of downstream objectives under varying operating conditions, with a substantial portion involving multivariate time-series tasks, such as state detection, fault diagnosis, prognostic health estimation, requiring models capable of reasoning over sensor streams. However, even the same task may demand distinct models under different conditions, producing a model library that grows with scale and complexity. One critical source for cross-condition generalization is covariate dependency—structured inter-channel relationships from components' mechanical, thermodynamic, and electrical interactions—stable as conditions shift. Some time-series foundation models (TSFMs) encode covariate dependency through large-scale pretraining, but a DT context adds two more: structure from target-task adaptation, and from DT representations. Whether these three sources capture complementary or redundant information is the central question this work investigates.

All three contributions are validated on remaining useful life (RUL) prediction using C-MAPSS, a well-established PMx benchmark with run-to-failure data across multiple operating conditions. First, we benchmark five TSFMs with frozen backbones, showing that pretrained covariate dependencies improve performance but fall short of dedicated state-of-the-art (SOTA) models, motivating additional sources that model covariate. Second, we propose a DT representation-informed fusion approach in which topological constraints from the asset's hierarchical graph encode mechanical interactions to shape cross-attention, ensuring sensor-level representations reflect physical structure rather than all-to-all interactions. Third, an ablation study across subsets demonstrates the three sources are complementary rather than redundant, and that a frozen backbone informed by DT-derived topology and lightweight adaptation matches or exceeds SOTA architectures, confirming TSFMs' potential when grounded in DT representations.

Speaker



Sizhe Ma
CMU

MS 095: Characterization and modeling of physical and chemical processes in porous materials across scales

2:15 PM – 3:35 PM | Location: HUMN 1B90

Chair(s): Mostafa Mobasher; Pania Newell; Sara Abedi; Manolis Vevakis; Jean-Michel Pereira; Giuseppe Buscarnera; Yanni Chen; Ghassan Shahin; Rigoberto Moncada

Moderators



Rigoberto Moncada Lopez
LLNL

ID 981: Stiffness properties of Living Building Material using Multi-phase Multi-scale Homogenization and Poromechanics approaches

2:15 PM – 2:35 PM

Author(s): Gadisa Merdassa, University of Colorado Boulder; Mija Hubler, University of Colorado Boulder

Understanding stiffness properties of Living Building Materials (LBMs) under load is crucial to address the emerging interest of their structural applications. Microstructures of LBMs are relatively complex (due to microbial activity, continuous enhancement of properties, and high porosity due to moisture-sensitive hydrogel binder desiccation with pore sizes spanning multiple length scales) compared to other construction materials. This study employs a combination of mean-field multiscale homogenization approaches at nanometer and micrometer length scales and the poromechanics approach at the millimeter scale to describe the effective stiffness properties of the material. Mercury Intrusion Porosimetry (MIP) is used to obtain pore parameters such as porosity, pore size distribution, and volume fraction of pores at micrometer and millimeter scales, together with Thermo-gravimetric Analysis (TGA) to determine the volume fraction of solid phases of the material at all length scales. The anticipated result demonstrates the importance of coupling between solid phases and pores to characterize the stiffness response of the LBMs contributing to the active scientific and engineering research area of understanding mechanical properties of LBMs.

Speaker



Gadisa Merdassa
University of Colorado Boulder

ID 205: Permeability tensor evolution: dynamic loading and crack geometry response

2:35 PM – 2:55 PM

Author(s): Rigoberto Moncada, Lawrence Livermore National Laboratory (LLNL); Efrem Vitali, Lawrence Livermore National Laboratory (LLNL)

The accurate representation of permeability is essential for flow applications in porous materials, including geological media. These applications are critical for attaining energy sustainability, managing water and mineral resources, and ensuring the safety and performance of infrastructure. Permeability variations are particularly sensitive for materials subject to variable and dynamic strain rates.

Furthermore, predicting permeability changes in low porosity rocks, where most flow-relevant voids are cracks, and other brittle materials is a daunting task. These crystalline materials have a very strong sensitivity to crack geometry and connectivity changes. Alterations in permeability can be of several orders of magnitude respect to their initial value without drastic changes in porosity. Moreover, permeability can significantly vary in some directions while staying relatively constant in others, depending on crack propagation.

To handle this complexity, instead of considering an isotropic-only response of permeability, we define evolution for a second order tensor. Thus, we have developed an evolution model for a permeability tensor based on crack geometry changes responding to high strain rates. Changes in microcrack structure are linked to modification of both permeability magnitude and directionality. The addition of directionality is essential for relating the stress tensor to permeability anisotropy.

For high strain rates, crack geometry can be affected by nucleation, propagation, coalescence, aperture changes and conservation of the aperture-to-length ratio. Our model incorporates these processes and has been able to produce realistic permeability evolution predictions. It is possible to account for permeability enhancement, reduction and stabilization. We can also identify conditions that increase anisotropy or permeability in one direction while decreasing in other directions. Hence, this work provides a comprehensive explanation of why and when permeability is modified under dynamic conditions.

Prepared by LLNL under Contract DE-AC52-07NA27344.

IM Number: LLNL-ABS-2014778

Speaker



Rigoberto Moncada Lopez

LLNL

ID 519: Modeling the Cone Penetration Test in Saturated Granular Soils Using Coupled LBM–DEM: Challenges and Capabilities

2:55 PM – 3:15 PM

Author(s): Sina Sadeghi, Virginia Tech; Reihaneh Hosseini, Virginia Tech

The cone penetration test (CPT) is one of the most widely used in-situ characterization methods in geotechnical engineering. Many correlations between CPT readings and soil properties have been developed empirically. Grain-scale numerical modeling can complement these correlations by providing mechanistic insight through direct representation of cone–grain interactions and offering a controlled setting to perform parametric studies. Discrete Element Method (DEM) simulations have been used for this purpose, but most prior work has focused on dry conditions. This work presents a coupled Lattice Boltzmann Method–Discrete Element Method (LBM–DEM) framework for simulating CPT in saturated granular materials, developed by linking an in-house LBM code with the open-source DEM software, YADE. The LBM component is well suited for pore-scale flow in complex geometries and is efficient and highly parallelizable, making it an attractive choice for coupling with DEM. In addition, the LBM formulation provides a clear pathway for future extension to multiphase flow, which is required for studying CPT in unsaturated soils. This study emphasizes practical aspects of coupled LBM–DEM modeling for CPT, with the goal of establishing simulation settings that produce stable and interpretable results. A systematic set of analyses is conducted to examine the cone-to-grain diameter ratio, the domain-to-cone size ratio and associated boundary effects. Furthermore, drainage conditions are explored through controlled changes in grain size and penetration rate. Based on these analyses, we discuss common sources of numerical instability in coupled LBM–DEM simulation of CPT, including time-step constraints, coupling frequency (DEM subcycling), LBM stability (e.g., low-Mach requirement), fluid relaxation parameters, and imposed penetration velocity. We also summarize unit conversion and scaling considerations needed to ensure consistent transfer of forces, pressures, and kinematics between the LBM and DEM solvers. The outcomes provide practical guidance for designing coupled LBM–DEM CPT simulations, including recommended dimensionless geometric ratios, simulation parameters, and checks to reduce boundary artifacts and improve numerical robustness. The study also outlines the range of drainage responses that can be investigated with the coupled approach and clarifies where additional development may be needed for higher penetration rates. Overall, the framework and observations support the use of LBM–DEM as a useful tool for studying CPT in saturated soils and as a foundation for future work on unsaturated conditions.

Speaker



Sina Sadeghi

Ph.D. student

ID 823: Multiscale analysis of volumetric deformation behaviour of plastic clays in the context of geological disposal of radioactive waste

3:15 PM – 3:35 PM

Author(s): Vidushi Toshniwal, Delft University of Technology, The Netherlands; Ties de Jong, Delft University of Technology, The Netherlands; Wout Broere, Delft University of Technology, The Netherlands; Michael Hicks, Delft University of Technology, The Netherlands; Anne-Catherine Dieudonné, Delft University of Technology, The Netherlands

Understanding the volumetric deformation behaviour of host formations is essential for the design and the assessment of long-term performance of geological disposal facilities (GDF) of radioactive waste. In clays envisaged as host formations for a GDF in several countries in Europe, macroscopic behaviour is governed by strongly coupled hydro-mechanical processes that depend on clay fabric and pore structure. Yet the microstructural mechanisms controlling anisotropic and time-dependent volumetric deformation remain insufficiently constrained.

This study investigates the volumetric deformation behaviour of plastic clay through a multiscale experimental approach linking macroscopic response to microstructural evolution. High-quality clay cores obtained at depths between 362 and 415 m beneath Delft, The Netherlands, enable laboratory investigations on minimally disturbed material. Anisotropic, time-dependent volumetric deformation is quantified using oedometer and constant rate of strain (CRS) tests on samples oriented parallel and perpendicular to the bedding plane. The macroscopic hydro-mechanical response is systematically linked to microstructural changes using complementary techniques, including scanning electron microscopy (SEM) and mercury intrusion porosimetry (MIP) allowing characterisation of pore structure across length scales ranging from 10 nm to 1 mm.

The results show that clay compressibility and permeability depend on clay content, stress history, and stress path. Post-testing pore size distributions consistently reveal a reduction in pore volume and a shift toward smaller pore diameters with increasing maximum applied load. These observations indicate rearrangement of clay microstructure, particularly in samples subjected to stress higher than the pre-consolidation pressure. SEM images further reveal a preferred orientation of clay layers after testing. Together, these results provide new experimental insight into the evolution of pore size distribution and microstructural changes under the applied testing conditions.

Speaker



Vidushi Toshniwal

Ph.D. Candidate | Delft University of Technology, The Netherlands

MS 031: Physics Meets AI: Foundation Models for Multiscale Mechanics

2:15 PM – 3:35 PM | Location: HUMN 1B80

Chair(s): Dibyajyoti Nayak; Dibakar Roy Sarkar; Somdatta Goswami

Moderators



Somdatta Goswami

Assistant Professor | Johns Hopkins University

ID 535: Bridging Length and Time Scales in Material Synthesis with Transferrable Representations

2:15 PM – 2:35 PM

Author(s): Wesley Reinhart, Pennsylvania State University; Isaiah Moses, Pennsylvania State University

The characterization of functional materials requires bridging disparate spatiotemporal scales, from atomic-scale lattice vibrations to macroscopic surface morphology. We discuss a machine learning framework that leverages foundational vision models and explainable AI to extract transferable representations of material behavior across these scales. We demonstrate two key innovations developed within the 2D Crystal Consortium Materials Innovation Platform (2DCC-MIP) at Penn State:

(1) We demonstrate a cross-modal generative learning architecture to reconstruct full spectroscopic signatures solely from surface features of thin films. By treating morphology as a surrogate for intrinsic material response, this model effectively learns a multiscale mapping between continuum-scale topography and atomic-scale vibration, enabling rapid in situ feedback. (2) We leverage an explainable computer vision pipeline to perform inverse analysis of synthesis conditions in SnSe thin films. We demonstrate how counterfactuals can act as physical hypotheses, identifying abstract morphological features (grain size, shape, and height variations) that correlate strongly with deposition parameters. These AI-discovered features are validated through atomistic simulations, providing a physics-informed understanding of how Se-passivation modulates growth.

These results demonstrate that large-scale pretrained architectures can be repurposed to solve specialized inverse problems in the physical sciences, providing new tools for interpreting characterization data and providing human-interpretable guidance for experimentalists. These methods help bridge the gap between nanoscale characterization and macroscopic material performance.

Speaker



Wesley Reinhart

Assistant Professor | Pennsylvania State University

ID 814: Reduced-Order Modeling for Multi-Mechanics Systems

2:35 PM – 2:55 PM

Author(s): Yeping Hu, Lawrence Livermore National Laboratory; Vic Castillo, Lawrence Livermore National Laboratory

High-fidelity computational mechanics simulations are indispensable for interrogating multiscale, multiphysics manufacturing phenomena, but their computational expense can impede broad design-space exploration, inverse problem solving, and time-critical decision support. This talk summarizes our efforts to integrate large-scale high-performance computing (HPC) simulation campaigns with scientific machine learning (SciML) to advance reduced-order modeling for multi-mechanics systems (ROM-MMS). We outline guiding principles for developing surrogate models that preserve essential physical properties while delivering substantial acceleration relative to full-order solvers, thereby enabling rapid prediction across process conditions and geometries. Using examples drawn from several manufacturing settings (e.g. glass manufacturing, near-net-shape processes, additive manufacturing, etc.), we discuss practical considerations that govern robustness, scalability, and eventual deployment. Overall, we present a pathway toward reliable, physics-informed surrogates that help bridge the gap between computational fidelity and operational speed.

Speaker



Yeping Hu

Research Scientist | Lawrence Livermore National Laboratory

ID 840: NOEM: Efficient and Scalable Finite Element Method Enabled by Reusable Neural Operators

2:55 PM – 3:15 PM

Author(s): Lu Lu, Yale University; Min Zhu, Yale University

The finite element method (FEM) is a well-established numerical method for solving partial differential equations (PDEs). However, its mesh-based nature gives rise to substantial computational costs, especially for complex multiscale simulations. Emerging machine learning-based methods provide data-driven solutions to PDEs, yet they present challenges, including high training cost and low model reusability. Here, we propose the neural-operator element method (NOEM) by synergistically combining FEM with operator learning to address these challenges. NOEM leverages neural operators (NOs) to simulate subdomains that require fine meshes in FEM. In each subdomain, an NO is used to build a single element, namely a neural-operator element (NOE). NOEs are then integrated with standard finite elements to represent the entire solution through the variational framework. Thereby, NOEM does not necessitate dense meshing and offers efficient simulations. We demonstrate the accuracy, efficiency, and scalability of NOEM by performing systematic theoretical analysis and numerical experiments, such as nonlinear PDEs, multiscale problems, PDEs on complex geometries, and discontinuous coefficient fields.

Speaker



Weihsang Ouyang

Postdoc | Yale University

ID 851: Toward Foundation-Ready Operator Surrogates in Mechanics: SetONet for Unstructured Functional Inputs

3:15 PM – 3:35 PM

Author(s): Stepan Tretiakov, The University of Texas at Austin; Xingjian Li, The University of Texas at Austin; Krishna Kumar, The University of Texas at Austin

Neural operators aim to learn mappings between function spaces and are increasingly used as data-driven surrogates for partial differential equations (PDEs) in engineering mechanics. A key practical barrier to deploying operator learners as reusable, foundation-model-like components is the mismatch between model input assumptions and how physical data are observed: sensor layouts change across experiments, sensors fail, and many forcings or material descriptors are naturally discrete point sets (e.g., point sources, particles, or samples from an underlying density) rather than values on a fixed grid. Standard Deep Operator Networks (DeepONets) encode the input function as values at a predetermined set of sensors, which precludes variable-input sampling and forces ad hoc preprocessing when inputs are unstructured. We introduce the Set Operator Network (SetONet), which preserves the DeepONet branch-trunk operator template but replaces the fixed-length branch with a permutation-invariant set encoder that consumes unordered location-value pairs with variable cardinality. SetONet augments coordinates with Fourier-feature positional encoding to capture spatial patterns across scales, and aggregates sensor embeddings with Deep Sets-style pooling, including a lightweight cross-attention pooling mechanism. The set encoder outputs operator coefficients compatible with the learned trunk basis functions, enabling the same synthesis rule as DeepONet at arbitrary query locations. We further study attention-based and quadrature-style coefficient heads that interpret set aggregation as sensor-weighted sums. Through careful design, SetONet maintains the same number of trainable parameters as a baseline DeepONet and can be used as a drop-in replacement that removes the fixed-sensor constraint without requiring rasterization or multi-stage preprocessing.

We validate SetONet on benchmark operator-learning tasks spanning canonical 1D operators (derivative and anti-derivative), nonlinear problems (1D Darcy flow and viscous Burgers), and a 2D plane-stress elastic plate with random boundary traction. In parameter-matched studies, SetONet achieves parity with DeepONet on fixed sensor layouts while maintaining accuracy when sensor locations vary during training and testing and when sensors are dropped at evaluation—settings where standard DeepONet is not directly applicable without imputation. Beyond variable sensing, SetONet directly targets unstructured inputs that arise in multiscale settings. We demonstrate end-to-end learning from point-cloud inputs on 2D heat conduction with multiple point sources, 2D advection-diffusion modeling chemical plumes, and optimal transport from sample-based source densities, eliminating rasterization and multi-stage pipelines. Across these point-cloud problems, SetONet outperforms the Variable-Input Deep Operator Network (VIDON) baseline while using smaller models and requiring less training time. By enforcing permutation invariance and decoupling the operator representation from a fixed discretization, SetONet offers a unified neural-operator interface for mechanics and multiphysics problems with heterogeneous, incomplete, or irregularly sampled inputs.

Speaker



Stepan Tretiakov

Graduate Student | The University of Texas at Austin

MS 040: Mechanics of Wood and Wood-Based Materials

2:15 PM – 3:35 PM | Location: CLUB 4-5

Moderatorss



Eric Landis

Professor | University of Maine



Luis Zelaya-Lainez

TU WIEN

ID 605: Rate Effects in the Fracture of Cross-Laminated Timber Beams

2:15 PM – 2:35 PM

Author(s): Chinmoyee Das, University of Maine; Sushma Mudbhari, University of Maine; Leonid Wlodkowski, University of Maine; ERic Landis, University of Maine

With the wide-scale adoption of mass timber in general, and cross-laminated timber (CLT) in particular, we are seeing wood resources being used in new and creative ways. In the case of CLT elements subjected to bending, shear loading across the grain produces the so-called rolling shear fracture mode, which in many practical cases governs the strength of the element. In the work described here, in order to examine rate effects, small scale CLT beams were subjected to both quasi-static loading and low velocity impact loading. The specimens were cut from 4 foot by 8 foot 3-ply panels into beams with a nominal 100 x 100-mm nominal cross section and a 1100-mm span. In the quasi-static tests, load was applied in displacement control at a rate of 2 mm/min, and were loaded until the midspan deflection was nominally 30 mm. In the impact tests a 9.1 kg shot put was dropped from a height of 4.5 m to provide an impact energy of 400 J. A high-speed camera recorded the impact and the resulting images were used for analysis. In both the quasi-static and impact tests, rolling shear in the cross-lam initiated failure, followed by delamination between the middle and top lamina. In the quasi-static tests, a single rolling shear fracture was observed in each test, but for the impact tests, there were multiple rolling shear fractures. An approximation of fracture energy was determined using the energy dissipated divided by the length of the crack growth, with crack growth separated by rolling shear and delamination. The quasi-static tests showed a nearly 75% higher fracture energy, however, we can assume that there is significant creep deformation in the quasi-static tests that do not occur in the impact tests. Current work is underway to better isolate and better quantify the relevant energy dissipation mechanisms. The work is aimed at supporting computational models for performance prediction of mass timber elements.

Speaker



Eric Landis

Professor | University of Maine

ID 468: Permeability homogenization for assessing and optimizing the infiltration performance of delignified wood

2:35 PM – 2:55 PM

Author(s): Stefan Scheiner, Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Austria; Markus Königsberger, Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Austria; Christian Hellmich, Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Austria; Josef Füssl, Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Austria

The production of transparent wood relies critically on effective delignification followed by controlled infiltration of a suitable polymer. Since the infiltration behavior is governed by the permeability of the delignified wood scaffold, understanding and predicting permeability across hierarchical length scales is essential for process optimization. Wood exhibits a highly complex multiscale structure, spanning from nanoscale cellulose assemblies and submicron pore networks to macroscopically anisotropic growth-ring patterns. Delignification alters this structure substantially by removing lignin, modifying pore connectivity, and increasing accessible void volume, which in turn affects the ease and uniformity with which polymer precursors can permeate the scaffold.

In this contribution, we present a multiscale modeling framework dedicated to the permeability upscaling of delignified wood, providing a predictive alternative to extensive experimental characterization for each wood-polymer combination. Building on continuum micromechanics-based homogenization, the approach integrates structural information across multiple observation scales. The model enables estimation of permeability tensors that reflect both the anisotropy and the hierarchical porosity of the treated wood.

Permeability upscaling is applied to (i) pristine wood, allowing for experimental validation through comparison with pertinent experimental data; (ii) delignified wood, for assessment of the aforementioned infiltration behavior; and (iii) also to transparent wood, to quantify the extent of permeability reduction upon occupation of the large pore spaces of wood by a polymer.

The resulting upscaled permeability predictions offer direct insight into polymer infiltration behavior – such as expected infiltration rates, preferred flow directions, and sensitivity to structural variations – thereby supporting the rational design of transparent-wood fabrication processes. Finally, we show how the homogenized permeabilities may serve as input parameters for Finite Element simulations on the structural scale.

Speaker



Stefan Scheiner

Dr. | TU Wien

ID 731: Two-Way Bending Response and Failure of CLT Panels with Different Load and Edge Restraint Conditions: Experiments and FE Analysis

2:55 PM – 3:15 PM

Author(s): Erkan Mutlu, Auburn University; Zachary Hayes, Auburn University; Kadir Sener, Auburn University; David Roueche, Auburn University; James Davidson, Auburn University

Cross-laminated timber (CLT) is an engineered wood product formed by stacking sawn lumber laminae with alternating grain orientations to exploit the direction-dependent behavior of orthotropic wood. Although CLT panels inherently provide two-way load resistance when supported on four sides, current design methodologies primarily treat them as one-way members, leaving much of their load-carrying potential unused. Fully benefiting from orthotropic action requires an understanding of the more complex load response and failure mechanisms that are dependent on loading type (e.g., single point vs. uniform), panel aspect (span-to-thickness) ratio, and boundary conditions (e.g., simple vs. fixed edges). Two-way behavior becomes especially critical under extreme loading scenarios such as blast, impact, or progressive collapse, where CLT panels may serve as wall or floor elements. This presentation focuses on experimentally observed behavior of CLT panels subjected to two-way bending under different load and support conditions.

This study investigates the load response and governing failure modes of Southern Yellow Pine CLT floor panels subjected to concentrated and uniform loading. A test matrix was developed by varying panel span, layup/layer count, major-axis orientation, and edge restraint conditions. Edge supports were implemented as simply supported (S) or clamped/fixed (F), including the fully simply supported case (SSSS) and mixed restraint configurations with three simply supported edges. During the two-way bending CLT tests, global response under loading was monitored via panel deflections as well as strain gauges at the outer plies. Rotations over the supported edges were also measured using inclinometers to quantify restraint effects and to track damage initiation and progression. Observed failure patterns were correlated with features of the load–deflection response to interpret stiffness changes and identify dominant mechanisms.

Complementary finite element analyses were conducted using LS-DYNA to replicate and predict experimental behavior. A layered finite element model was developed with orthotropic wood behavior represented using MAT_143, together with appropriate contact and boundary conditions to capture load introduction and support interactions. Agreement between experiments and simulations was evaluated based on global stiffness and capacity responses, as well as the inferred governing failure mechanism. Numerical results were further used to examine internal layup stress and strain distributions leading to failure and to aid in interpreting collapse mechanisms observed during testing.

Overall, the combined experimental and computational results are used to demonstrate the two-way bending behavior of CLT panels and highlight the influence of boundary restraint, orthotropy, and layup on response. The findings delineate the transition between global bending-governed behavior and localized punching or bearing failures, providing insight for design and extreme event evaluation.

Speaker



David Roueche

Gottlieb Associate Professor of Civil and Environmental Engineering | Auburn University

MS 046: Self-Healing Structural and Material Systems

2:15 PM – 3:35 PM | Location: CASE E230

Chair(s): Dryver Huston; George Voyiadjis; Sanhita Das

Moderators



Dryver Huston

Prof. | University of Vermont

ID 910: Assessing, modeling, and mitigating shrinkage in earth materials: a Swiss perspective

2:15 PM – 2:35 PM

Author(s): Yi Du, 1 Chair of Sustainable Construction, ETH Zurich; 2 Laboratory of Concrete and Asphalt, Empa; Guillaume Habert, Chair of Sustainable Construction, ETH Zurich; Ellina Bernard, 1 Chair of Sustainable Construction, ETH Zurich; 2 Laboratory of Concrete and Asphalt, Empa; Pietro Lura, 2 Laboratory of Concrete and Asphalt, Empa; 3 Institute for Building Materials, ETH Zurich

Poured earth addresses the processing challenges of traditional earthen building while leveraging existing concrete production infrastructure. However, its significant shrinkage, especially when no hydraulic binders are added, restricts its wider use. Shrinkage of earth materials primarily arises from water evaporation and the buildup of capillary stress that compresses the solid matrix. During the drying process, the poured earth transitions from a saturated to an unsaturated regime, accompanied by water loss and a corresponding increase in matric suction, which drives the material to deform. To date, no measurement method has been documented that can continuously monitor the shrinkage of poured earth from the fresh to the hardened stage. In this study, part of Innosuisse's "Think Earth" Regenerative Construction Flagship Project, an experimental framework was established to assess, evaluate, and mitigate shrinkage in earth materials. A new experimental setup was designed to enable continuous measurements of shrinkage from sample placement through the hardened phase, using Linear Variable Differential Transformer (LVDT) sensors. A model earth material composed of sand, silt, and a modest amount of clay was studied under different conditions. Free shrinkage was quantified under rapid drying conditions, using semi-cylindrical specimens to reduce geometric constraints. The measured shrinkage is interpreted and evaluated using poroelastic theory. In parallel, dispersant, surfactant, and bio-based additives designed to reduce shrinkage were further examined. The findings demonstrate that the combined experimental and theoretical analysis establishes a coherent approach to assess shrinkage, link it to fundamental poromechanical mechanisms, and evaluate mitigation strategies for earth-based construction materials.

Speaker



Yi Du

ETH/Empa

ID 356: Self-healable, Recyclable and Reconfigurable Electronics for Wearable Applications

2:35 PM – 2:55 PM

Author(s): JIANLIANG XIAO, University of Colorado Boulder

Liquid metal (LM) exhibits a distinct combination of high electrical conductivity comparable to that of metals and exceptional deformability derived from its liquid state, thus it is considered a promising material for high-performance soft electronics. However, rapid patterning LM to achieve a sensory system with high sensitivity remains a challenge, mainly attributed to the poor rheological property and wettability. Here, we report a rheological modification strategy of LM and strain redistribution mechanics to simultaneously simplify the scalable manufacturing process and significantly enhance the sensitivity of LM sensors. By incorporating SiO₂ particles into LM, the modulus, yield stress, and viscosity of the LM-SiO₂ composite are drastically enhanced, enabling 3D printability on soft materials for stretchable electronics. The sensors based on printed LM-SiO₂ composite show excellent mechanical flexibility, robustness, strain, and pressure sensing performances. Such sensors are integrated onto different locations of the human body for wearable applications. Furthermore, by integrating onto a tactile glove, the synergistic effect of strain and pressure sensing can decode the clenching posture and hitting strength in boxing training. When assisted by a deep learning algorithm, this tactile glove can achieve recognition of the technical execution of boxing punches, such as jab, swing, uppercut, and combination punches, with 90.5% accuracy. We also explored heterogeneously integrating rigid, soft and liquid materials through a low-cost and scalable fabrication method. This system uses covalently adaptable network polymer as the matrix, liquid metal as the circuitry and high-performance semiconductor chips as the functional components. Such multifunctional wearable electronic system combines advances in materials, chemistry and mechanics to enable superior stretchability, self-healability, recyclability and reconfigurability. High-performance sensing of electrocardiograph (ECG), temperature, motion, strain and acoustic signals are demonstrated. Such electronic systems can find applications in many areas, including health care, robotics, and prosthetics, and can benefit the wellbeing, economy, and sustainability of our society.

Speaker



Jianliang Xiao

Associate Professor | University of Colorado Boulder

ID 712: Self-Stressing Fibers and Yarns as Promoters of Self-Healing Cementitious Materials

2:55 PM – 3:15 PM

Author(s): Emma McDonald, University of Vermont; Mohammad Abdul Qader, University of Vermont; Mandar Dewoolkar, University of Vermont; Dryver Huston, Dryver Huston

This presentation will discuss the use of self-stressing fibers to promote self-healing in cementitious materials. The autogenous healing of concrete and cement by in-filling of tight cracks is a well-documented phenomenon, largely driven by the hydration of free lime in the cement. Clades of free lime have recently been discovered as a more active form of self-healing cement in Roman concrete. The healing is easier with tight cracks. Prestressing and the presence of fibers reduces the width of cracks in cement. Functionalized fibers that apply prestress have the potential to further enhance the performance of crack width reduction measures. We examine three forms of self-stressing fibers for this application: 1. Chitosan fibers that shrink in high-pH, 2. Pre-loaded steel rings with soluble elements that dissolve and release the load to prestress, and 3. Twisted chitosan-soaked yarns that act as Baughman actuators for a more aggressive shrinking action. A variant on the twisted yarn is to use them as wicking media for healing agents, such as free lime. Operating principles and the results from proof-of-concept experiments will be presented.

Speaker



Dryver Huston

Prof. | University of Vermont

ID 241: Seawater mineralization pathway for carbon-negative aggregate production

3:15 PM – 3:35 PM

Author(s): Daiki Shoji, Subsurface Opportunities and Innovations Laboratory, Department of Civil and Environmental Engineering, Northwestern University; Alessandro F. Rotta Loria, Subsurface Opportunities and Innovations Laboratory, Department of Civil and Environmental Engineering, Northwestern University

Global warming necessitates scalable strategies that can both store and utilize CO₂ to mitigate climate change, particularly within the cement and concrete industry, which is responsible for substantial CO₂ emissions and relies heavily on environmentally extracted aggregates such as sand. Carbon mineralization offers a promising pathway to address both challenges simultaneously, provided that processing methods enable control over aggregate microstructure and in engineering performance. Here, we present the first experimental use of an ex-situ rotary carbonation process that converts seawater-sourced alkaline mineral powders into cohesive, sand-sized aggregates through carbonation-induced self-binding, without the addition of any cementitious, polymeric, or other chemical binding agents at any stage of processing. The process integrates wet granulation and accelerated carbonation, enabling direct links between processing conditions and microstructural evolution. Optimal processing parameters are identified to control aggregate size, morphology, and mechanical strength, supported by a theoretical interpretation of the physicochemical reactions governing the process. Initially loose, micron-scale Mg(OH)₂- and CaCO₃-rich powders recovered from seawater are transformed into millimeter-scale aggregates within a rotating drum operated under controlled humidity and a CO₂-containing atmosphere. Thin surface water films form on the hydrophilic powders through adhesive mineral–water interactions and cohesive water–water interactions. These films promote particle coalescence during wet granulation while simultaneously facilitating accelerated carbonation. Carbonation of Mg(OH)₂ in the interfacial water films leads to the formation of hydrated magnesium carbonate binding phases through their dissolution and reprecipitation that bridge individual particles, reduce interparticle space, and impart mechanical integrity to the aggregates. Water content is found as the key process variable that governs water film thickness, carbonation kinetics, and ultimately CO₂ sequestration efficiency. The collective findings reveal that seawater-sourced alkaline feedstocks can be used to manufacture artificial aggregates that absorb up to 30.8 wt.% CO₂ and exhibit physical and mechanical properties comparable to those of aggregates produced from commercial feedstocks and natural pumice sand. Environmental and economic analyses further indicate the potential for carbon-negative aggregate production, with estimated costs ranging from \$51 to \$89 per ton of aggregates. Overall, this work establishes a clear processing–microstructure–property framework for rotary carbonation and highlights seawater-derived alkaline minerals as viable feedstocks for scalable, low-carbon aggregate manufacturing.

Speaker



Daiki Shoji

Ph.D. student | Northwestern University

MS 103: Industry Challenges in Engineering Mechanics (ICiEM)

2:15 PM – 3:35 PM | Location: CASE E240

Chair(s): Kundan Goswami; Gourab Ghosh; Rudraprasad Bhattacharyya

Moderators



Rudraprasad Bhattacharyya

Engineering Analyst | Cronus Technology

ID 157: Integrity Assessment of Subsea Jumpers using Numerical Modeling

2:15 PM – 2:35 PM

Author(s): Xiang Zhou, Cronus Technology; Rudraprasad Bhattacharyya, Cronus Technology

Subsea jumpers are critical components in offshore production systems, providing flexible connections between subsea structures and pipelines. Ensuring their structural integrity throughout the service life is essential to maintain safety, reliability, and uninterrupted operations. Integrity assessment of subsea jumpers typically involves evaluation of design loads, installation effects, and in-service conditions, including internal pressure, thermal expansion, hydrodynamic forces, fatigue, corrosion, and accidental damage. Advanced analytical methods, numerical modeling, and inspection data are combined to assess stresses, fatigue life, and potential failure modes. The assessment supports verification of compliance with applicable industry codes and standards, identification of integrity threats, and development of inspection, monitoring, and mitigation strategies. A robust integrity assessment framework enables informed decision-making, life extension, and risk reduction for subsea jumper systems. This presentation will present how numerical modeling techniques are used to assess jumpers in-service.

Speaker



Rudraprasad Bhattacharyya

Engineering Analyst | Cronus Technology

ID 551: Fatigue Design and Evaluation for Welded In-Plane Gusset Joints

2:35 PM – 2:55 PM

Author(s): Jeong Hong, Thornton Tomasetti; Xin Chu, Thornton Tomasetti; Vahid Barzegar, Thornton Tomasetti; Yuan Tian, Thornton Tomasetti; Zhi Zhang, Thornton Tomasetti

Welded in-plane gusset joints have been used in many industries, including steel bridges, cranes, and offshore applications. Codes and Standards-based fatigue design and evaluation for in-plane gusset joints have been categorized mainly by base plate length and width, and weld toe ground radius. The majority of the category-based S-N curves exhibit excessive conservatism relative to fatigue test data under as-welded conditions. Though the fatigue S-N behavior for double-sided gusset joints is different from that for single-sided gusset joints, the categorization method does not distinguish between single-sided and double-sided gussets. Additionally, even though the fatigue S-N slope for weld toe ground data sets is observed to be shallower than that of as-welded fatigue data sets, the fatigue S-N slope is fixed as 3 regardless of weld toe conditions, such as as-welded or weld toe-grounded. This results in a non-conservative fatigue design and evaluation at a short fatigue regime.

In order to overcome the limitations of the current categorization procedure, the FEA-based equivalent structural stress range parameter and its Master S-N curve, adopted by ASME BPVC VIII-2 and API 579-1/ASME FFS-1, was applied to welded in-plane gusset joints. When the effective thickness based on the proposed failure criteria was applied, all fatigue data from the in-plane gusset joints were observed to be consolidated within the Mean - 2*STD (95.4% confidence interval) of the master S-N curve with a slope of 3.125, regardless of the sizes, shapes, and thicknesses of the gusset and the base plate, and number of gussets for as-welded fatigue data sets.

Some applications can use rigorous failure criteria, such as finite crack sizes, rather than complete failures. The modified equilibrium-based structural stress procedure was proposed for partial failure cases to consider the rigorous failure criteria. Once the modified procedure was applied, the partial-failure data sets were combined with the complete-failure data sets. Therefore, the design S-N curve for the complete failure data sets could be equally applicable to that for partial failure data sets.

This proposed method was also applied to weld toe-ground fatigue test data sets; all data sets were consolidated within a narrow scatter band regardless of the size of the weld toe ground radius, the sizes, shapes, and thicknesses of the gusset and the base plate, and the number of gussets. Using statistical analysis, the S-N curve for design and evaluation for ground in-plane joints with a slope of 5 and the same STD as the Master S-N curve was constructed. Partial failure data sets showed reasonable consolidation with the complete fatigue data sets.

Speaker



Jeong Hong

Vice President | Thornton Tomasetti

ID 737: Engineering Mechanics Challenges in Mitigating Wind Damage From Lab Uplift Tests to Real Asphalt Shingle Roofs

2:55 PM – 3:15 PM

Author(s): Arpit Anil Bhusar, SageSure; Jorge Santiago-Hernandez, SageSure; David Prevatt, University of Florida; Daniel Smith, SageSure

Over 90% of U.S. single-family homes are roofed with asphalt shingles, and wind-induced roof-cover damage remains a dominant contributor to insured losses during hurricanes. While wind uplift mechanisms are well characterized under controlled laboratory conditions, translating this knowledge into effective, scalable mitigation strategies for existing residential roofs has proven challenging. In particular, limited field data, uncertain roof condition assessments, and degradation of shingle adhesive bonds over time complicate vulnerability estimation and performance evaluation of mitigation interventions.

This work focuses on a mechanics challenge central to this gap. First, the insurance industry currently estimates roof wind vulnerability using limited inspection data and uncertain roof age assessments. Critical drivers of roof resilience remain unobserved, especially how in-plane tensile stresses impact performance of adhesive sealants in asphalt shingles, which evolves with diurnal thermal cycling and material aging from UV and IR exposure and is the leading cause of shingle failure in high wind events. Asphalt shingles that have become unsealed due to degradation of the factory-applied sealant strip, are a common precursor to shingle uplift and tear-off under wind loading. Second, the industry lacks labs and testing facilities and testing protocols to evaluate the performance and effectiveness of resealed shingles. As part of an industry-academia collaboration, the University of Florida (UF) contributes academic perspective by synthesizing relevant literature, drawing on prior asphalt shingle research, and providing technical commentary on the experimental framework and interpretation of results.

Preliminary findings suggest that shingle resealing can measurably alter uplift response and failure progression under wind loading, highlighting the importance of adhesive condition as a latent variable in roof vulnerability modeling. These results highlight the importance of incorporating adhesive degradation into roof vulnerability modeling and motivate development of standardized test methods for evaluating resealing interventions. The presentation concludes by discussing research and partnership opportunities to advance experimental protocols, improve field-to-lab translation, and enable scalable roof resilience strategies for hurricane-prone regions.

Speaker



Arpit Bhusar

Senior Manager - Innovation | SageSure Insurance

ID 816: Environmental Effects on the Natural Frequency Variability in a Jacket-type Offshore Structure: A Case Study of the Gageocho Ocean Research Station

3:15 PM – 3:35 PM

Author(s): Byungmo Kim, Korea Maritime and Ocean University; Sunho Park, Korea Maritime and Ocean University; Seung-Hyun Ha, Korea Maritime and Ocean University; Kideok Do, Korea Maritime and Ocean University; Sangmin Park, Korea Institute of Ocean Science & Technology

South Korea operates three comprehensive ocean research stations, which are jacket-type structures instrumented to monitor over 20 environmental parameters, such as waves, wind, and temperature. Focusing on the Gageocho Ocean Research Station, this study investigates the temporal variability of natural frequencies extracted from long-term inclination data under varying environmental conditions. The results exhibited distinct short-term diurnal cycles and long-term seasonal patterns. Statistical analysis confirmed that these frequency variations follow a Normal distribution. To identify the governing factors, the relationships between structural response and environmental data were analyzed. The results indicated that ambient temperature is the dominant factor, showing a weak positive linear correlation with natural frequencies, whereas sea surface level had a negligible effect.

Speaker



Byungmo Kim

Assistant professor | Korea Maritime and Ocean University

MS 102: Embedding AI in Structural Mechanics for Undergraduate Engineers

2:15 PM – 3:35 PM | Location: UMC 247

Chair(s): Jieun Hur

Moderators



Adriana Trias Blanco

Assistant Professor | Rowan University

ID 720: Integrating Research, Capstone Design, and Competition Teams for Experiential Learning in Civil Engineering

2:15 PM – 2:35 PM

Author(s): Hyunjoong Kim, Liberty University

This paper presents a research-integrated educational framework that includes undergraduate research, capstone design projects, and student competition teams. The approach is demonstrated through an ML-based structural force identification research project that connects physical testing, numerical modeling, and data-driven analysis.

An ASCE Steel Bridge Competition team provides a student-designed physical bridge model, which serves as a testbed for research-oriented activities. A capstone design project is used to develop experimental setups and sensing systems for laboratory testing. Undergraduate research students contribute by developing numerical models, generating simulation data, and implementing machine learning models to connect experimental and computational components.

This vertically integrated framework enables students to engage in learning experiences that are difficult to achieve in traditional classrooms, including experimental design, model validation, and the interaction between physics-based modeling and data-driven methods. The proposed approach demonstrates a practical and scalable pathway for incorporating advanced research topics into civil engineering education under constrained resources.

Speaker



Hyunjoong Kim

Assistant Professor | Liberty University

ID 696: The Scholar Bridge

2:35 PM – 2:55 PM

Author(s): Adriana Trias Blanco, Rowan University

Rowan University distinguishes itself through a hands-on pedagogical approach that bridges the gap between theoretical classroom concepts and real-world engineering challenges. Rowan offers undergraduate students the opportunity to be involved in state-of-the-art research projects through the Clinics course, whose topics typically derive from ongoing faculty research. Clinics are offered in every semester, and during their Junior and Senior years, students get to select the clinic of their choice. Students go through a matching process, similar to that in medical school, in which professors offer a variety of projects to choose from, and students rank their preferences, ensuring they are deeply invested in their assigned research area. One project, The Scholar Bridge, is tailored to students interested in structural engineering as it covers non-destructive testing, structural health monitoring, and remote sensing, among other related concepts. This is an immersive, hands-on experience where students collect, process, and analyze data in the structures lab. Some project examples are (a) lateral deflection characterization of vertical structures, (b) bridge support condition assessment, (c) bridge vertical clearance capturing through mobile LiDAR, and (d) structural vibration detection via remote sensing. This clinic project has become quite popular among Civil Engineering students, and to promote popularity, students are welcome to suggest new research areas to explore in the following semesters. To fulfill the curricular requirements and demonstrate professional competency, students must produce comprehensive deliverables, including a technical final report and a formal presentation delivered to their peers, and in some cases to their funding agencies, that detail critical lessons learned throughout the research cycle. Beyond the classroom, some students go the extra mile by submitting abstracts and papers to participate in regional and national conferences with a great success rate. Additionally, this experience can be added to their resume, and the experience gained has been recognized by employers.

Speaker



Adriana Trias Blanco

Assistant Professor | Rowan University

ID 829: Retrieval-Augmented Multi-Agent Self-Correcting AI for Civil Engineering: From FE Exam Benchmarking to Design Generation and Autonomous Evaluation

2:55 PM – 3:15 PM

Author(s): Saurav Silwal, University of Houston; Joshua Gao, University of Houston; Subin Varghese, University of Houston; Saurav Silwal, University of Houston

Large language models (LLMs) are increasingly being explored in civil engineering for their ability to understand technical documents and interpret design codes. However, when used without proper augmentation, they frequently hallucinate or produce mathematically inconsistent results, making reliability a critical concern. Different Retrieval-Augmented Generation (RAG) strategies have emerged to address this, yet they have not been systematically compared in the civil engineering domain. To address this need, we first benchmarked twelve state-of-the-art LLMs on Fundamentals of Engineering (FE) Civil examination questions across different augmentation strategies, where agentic RAG emerged as the superior approach. Using this finding as a foundation, we scaled the agentic RAG approach into a multi-agent framework for fully automated, code-compliant structural design, in which specialized agents handle code retrieval, structural calculations, validation, and iterative self-correction. The framework was tested on 33 reinforced concrete (RC) beam configurations with varying geometry, materials, and loading conditions, successfully producing code-compliant designs in all cases. We further developed an RAG-based autonomous evaluation system that dynamically extracts assessment criteria from reference solutions, eliminating the need for manually crafted rubrics. This evaluator showed excellent agreement with traditional hardcoded scoring (Pearson's $r = 0.976$). Final design accuracy was validated against ETABS finite element analysis and design, achieving near-identical results ($r \geq 0.9$). This work establishes agentic RAG as the superior augmentation strategy for civil engineering tasks and demonstrates a complete pipeline for code-compliant structural design with transparent calculations and evaluation.

Speaker



Saurav Silwal

PhD Student | University of Houston

Moderatorss



Wei Song



Amirali Najafi

Assistant Professor | Texas A&M University

ID 375: Multi-DOF Force Control Design for Multi-Physics Systems in Hydrodynamic Real-time hybrid simulation of Floating Offshore Wind Turbine Prototyping

2:15 PM – 2:35 PM

Author(s): Yun Ni, Stanford University; Akiri Seki, Stanford University; Bret Bosma, Oregon State University; Ted Brekken, Oregon State University; Bryson Robertson, Oregon State University; Andreas Schellenberg, Maffei Structural Engineering; Pedro Lomonaco, Oregon State University; Barbara Simpson, Stanford University

Real-time hybrid simulation (RTHS) is a cyber-physical testing methodology with growing potential for model-scale prototyping of floating offshore wind turbines (FOWTs). In hydrodynamic RTHS (hydro-RTHS), aerodynamic loads are emulated by actuators, while the floating FOWT model is subjected to physical wave excitation. To enable 6-degree-of-freedom (6-DOF) force control, a lightweight industrial robotic arm, enabled by electric servomotors, was adopted in place of conventional hydraulic actuators due to its compact configuration and improved force resolution in low-load regimes. However, hydro-RTHS for FOWT prototyping presents requirements for robotic actuation that differ from conventional robotic applications, including 6-DOF force control under platform motions, small-scale force settings, and strict real-time delay requirements. The multi-physics hydro-structural environment, as well as limited time for system identification and controller tuning during prototyping, introduce significant uncertainties and nonlinearity in both the robotic arm and the environment, limiting the applicability of fully model-based control approaches or traditional linear control approaches. Thus, this study discusses control design considerations for achieving 6-DOF force control through task-space explicit force control and joint-space pose-keeping objectives, augmented by an adaptive feedforward compensator (AFC) to compensate for delays. Prototype FOWT experiments conducted under both wind-only and combined wind-wave operational conditions demonstrate satisfying force tracking performance in a coupled hydro-structural environment with minimal prior system information. Limitations of the current approach and directions for future model-based and data-driven extensions are discussed to improve performance under larger wave disturbances.

Speaker



Yun Ni

Miss | Stanford University

ID 137: Experimental Study of Adaptive Compensation in Multi-Axial Real-Time Hybrid Simulation

2:35 PM – 2:55 PM

Author(s): Santiago Ruiz, University of Alabama; Wei Song, University of Alabama

While RTHS enables high-fidelity testing of complex systems, transfer system and physical specimen dynamics introduce time delays and actuator amplitude attenuation, causing desynchronization at the numerical-physical interface that compromises the stability and accuracy of RTHS. Adaptive compensation strategies address these limitations by continuously updating parameters in real-time, accounting for varying time-delay behavior. Still, their development has largely been confined to single-input single-output systems. This restriction is critical because many civil infrastructure systems exhibit inherently multi-axial and coupled dynamic responses. Advancing multi-axial RTHS (maRTHS) capabilities is therefore essential for realistic simulation of these systems; however, maRTHS presents significant challenges due to increased control dimensionality. Although recent numerical studies have demonstrated the potential of adaptive compensation frameworks for maRTHS, experimental evidence supporting their performance remains limited. This study addresses this gap by experimentally validating an adaptive compensation strategy for a multi-axial RTHS system under varied loading conditions. The compensator employs an inverse-dynamics-based control law combined with nonlinear parameter estimation algorithms. The experimental setup employs two orthogonally arranged linear actuators connected to a physical specimen that enables coupled rotational motions about two axes. Numerical and experimental results demonstrate accurate actuator tracking and robust interface synchronization, confirming the feasibility and effectiveness of the proposed adaptive compensation for practical maRTHS applications.

Speaker



Santiago Ruiz

PhD. Candidate | The University of Alabama

ID 529: Multi-axis Mixed-mode Hybrid Simulation for Examining FRP-Retrofitted RC Columns

2:55 PM – 3:15 PM

Author(s): Edwin Patino, Purdue University; Mohamed Gomaa, Purdue University; Juan Nicolas Villamizar, Purdue University; Shirley Dyke, Purdue University; Julio Ramirez, Purdue University

Non-ductile reinforced concrete (RC) columns in old structures pose a significant seismic risk due to design and construction criteria that did not align with current standards, often leading to a non-ductile behavior of these elements. While Fiber-Reinforced Polymer (FRP) wrapping is a widely adopted retrofit strategy due to its high elastic modulus, straightforward and non-invasive application, evaluating its effects and efficacy within a structural system remains a challenge. This study utilizes hybrid simulation to investigate the interaction between a physical column specimen in its deficient and retrofitted conditions and a numerical structural frame.

The experimental methodology integrated OpenSeesPy and Speedgoat via a TCP/IP communication to interface the numerical and physical substructures. This integration was performed within MATLAB/Simulink, which acted as the middleware. The numerical model consisted of a four-story, three-bay RC frame with non-ductile elements. The physical specimen, a square non-ductile RC column with a deficient lap-splice connection, was tested using a three-degree-of-freedom assembly with one horizontal and two vertical actuators to enforce load and boundary conditions at the control point on the specimen located at the top column joint. The same physical specimen was retrofitted with FRP wrapping with the objective of preventing a shear-controlled failure and tested under the same loading conditions. To manage the coupled degrees of freedom and the mixed-mode control demands from the boundary and load conditions, a cascade control strategy was implemented to ensure stability and command tracking for the control point's rotation and axial load.

Experimental results demonstrate the efficacy of the multi-actuator control strategy, which was able to maintain complex boundary conditions while applying displacement commands from the simulation. Additionally, the results demonstrate the efficacy of the FRP retrofit, which improved the specimen's failure mode from brittle to ductile. This enhancement reduced lateral drifts in the first story, effectively preventing a soft-story mechanism. This study highlights the potential of multi-axis hybrid simulation as a tool for assessing retrofit strategies under realistic loading conditions on stiff specimens.

Speaker



Edwin D. Patino

Mr. | Purdue University

ID 674: Evaluating bandgap performance of seismic metamaterials using real-time hybrid simulation

3:15 PM – 3:35 PM

Author(s): Tao Zhang, Purdue University; Luz Maria Agudelo Urrego, Purdue University; Mohamed Gomaa, Purdue University; Tyler Martin, Washington University at St. Louis; Arun Prakash, Purdue University; Christopher Gill, Washington University at St. Louis; Shirley Dyke, Purdue University

Seismic metamaterials (SMs) have the potential to drastically mitigate the impact of seismic events on critical infrastructure. Through tailored microstructural configurations, SMs can achieve targeted objectives, most notably the creation of frequency bandgaps for wave attenuation. However, physical testing of large SM systems, either in the laboratory or in the field, is usually infeasible or prohibitively expensive.

In this study, we use real-time hybrid simulation (RTHS) – a novel experimental technique that combines physical testing and numerical simulation to evaluate the performance of different SMs. While RTHS allows for the testing of large-scale structures, it introduces inevitable delays due to communication between physical and numerical subsystems, actuator dynamics, and the time needed to solve the numerical model. In the frequency domain, these time delays manifest as phase shifts that can distort the apparent dynamic stiffness and damping of the system, leading to misrepresentation of the bandgap characteristics of the SM.

We conduct RTHS on 3D printed scaled specimens of SMs with different microstructures on an electric shake table driven by a nonlinear sliding mode controller with an Unscented Kalman Filter (UKF) for robust state estimation. An in-house Linux-based real-time execution platform is used to coordinate the computational and control tasks. RTHS results are compared to full numerical simulations and baseline dynamic tests of 3D-printed structures coupled to the SMs. The control loop is operated at different execution frequencies (256 Hz – 2048 Hz) to explicitly account for the corresponding time-delays and their effect on the performance of the SMs. We analyze how these delays degrade wave attenuation and shift bandgap frequencies and discuss compensation strategies to ensure accurate spectral characterization of SMs with RTHS.

Speaker



Tao Zhang

Student | Purdue University

MS 096: Coupled Multi-Physics Mechanics of Geomaterials for Energy and Environmental Applications

2:15 PM – 3:35 PM | Location: UMC 382-384-386

Chair(s): Angelica Tuttolomondo; Anne-Catherine Dieudonné

Moderators



Anne-Catherine Dieudonné

Associate Professor Multiphysics Geomechanics | Delft University of Technology

ID 362: Evolution of the mechanical properties of olivine due to thermal and chemical alteration: high-fidelity ultrasonic characterization by viscoelastography

2:15 PM – 2:35 PM

Author(s): Andrei S. Severin, Department of Civil, Environmental, and Geo- Engineering, University of Minnesota Twin Cities, Minneapolis, MN; Prasanna Salasiya, Department of Civil, Environmental, and Geo- Engineering, University of Minnesota Twin Cities, Minneapolis, MN; Pouyan Asem, Department of Civil Engineering, University of Texas Permian Basin, Midland, TX; Joseph F. Labuz, Department of Civil, Environmental, and Geo- Engineering, University of Minnesota Twin Cities, Minneapolis, MN; Bojan B. Guzina, Department of Civil, Environmental, and Geo- Engineering, University of Minnesota Twin Cities, Minneapolis, MN

Geologic carbon sequestration through mineral carbonation offers a permanent solution to reducing atmospheric CO₂. In this process, CO₂-enriched fluids are converted into stable carbonate minerals within ultramafic rocks. Nevertheless, fundamental questions remain in the details: specifically, how do geochemical reactions and hydromechanical behaviors intertwine to influence the permeability and reactive surface area across space and time? These coupled factors ultimately dictate whether mineralization accelerates or stalls. In terms of field applications, the key challenge is to understand and monitor the macroscopic fingerprint of such coupled pore-scale processes, using, for instance, seismic waves. In this work, we examine changes in the viscoelastic properties of an olivine-rich, sheet-like rock specimen, which serves as a laboratory surrogate for field-scale seismic surveys. To decouple the competing effects of reaction-driven cracking and dissolution, we pursue a tripartite experimental sequence. First, we establish a baseline “viscoelastic” map for the intact rock. Next, we damage the rock locally at two distinct locations by (a) heating the specimen to 500 °C (thermal expansion-driven micro-cracking), and (b) exposing the specimen to reactive flow in a direction perpendicular to the plane of the specimen (dissolution). To capture the macroscopic fingerprint of such pore-scale processes, we utilize Scanning Laser Doppler Vibrometry (SLDV) to measure (with sub-millimeter resolution) the in-plane ultrasonic wavefields propagating through the specimen. To translate such interior kinematic data into the maps of (heterogeneous) elastic and dissipative rock properties, we employ the Modified Error-in-Constitutive-Relation (MECR) approach to viscoelastography. In short, the MECR functional is formulated as a linear combination of the ECR functional and kinematic (data) mismatch, weighted by a regularization parameter. Here, the ECR functional utilizes full-field ultrasonic motion data to quantify the discrepancy between constitutively-compatible and dynamically-compatible stress fields, while the kinematic mismatch term measures the difference between simulated and observed displacements. For generality, the rock's viscoelastic behavior is described within a thermodynamic framework of generalized standard materials (GSM), characterized by the Helmholtz free energy and a dissipation potential. These potentials and their energetic conjugates are then used to compute the sought MECR functional, whose minimization (subject to the PDE constraint of balance of linear momentum) reveals the maps of viscoelastic rock properties over the observation window. Our results quantify how the “seismic” signatures (wave velocities and attenuation) of rock evolve due to local micro-cracking and dissolution. By integrating such observations with micro-CT images of the pore-scale structure, we shed light on the key question of how the evolution of mineralized CO₂ reservoirs can be monitored in the field.

Speaker



Andrei Severin

Graduate Research Assistant | University of Minnesota

ID 401: Thermo-Hydro-Mechanical Simulation of Compacted Bentonite: Analysis of High-Temperature CIEMAT Column Tests

2:35 PM – 2:55 PM

Author(s): Ju Sung Park, In Ha University; Sung In Cho, In Ha University; Yu Jin Kim, In Ha University; Seon Hong Na, In Ha University

Deep geological disposal of high-level radioactive waste (HLW) relies on robust Engineered Barrier Systems (EBS), typically composed of compacted bentonite, to isolate spent nuclear fuel from the surface environment. In repository settings, the buffer material faces extreme boundary conditions: thermal loads from decay heat and hydraulic pressure from the surrounding host rock. Therefore, reliable performance assessment requires a fundamental understanding of the coupled Thermo-Hydro-Mechanical (THM) behavior of bentonite. This study presents a comprehensive numerical validation of the Barcelona Basic Model (BBM) against the CIEMAT column tests (Villar et al., 2014), a benchmark for high-temperature unsaturated soil behavior.

The CIEMAT experiments subjected a bentonite column (7 cm diameter, 50 cm height) to constant bottom heating (100–140 °C) and simultaneous top hydration. This configuration imposed counter-current thermal and hydraulic gradients, inducing complex multiphysics interactions. Monitoring data revealed that moisture transport near the heat source was dominated by vapor diffusion rather than liquid flow, leading to the formation of a persistent desaturated zone. Furthermore, the development of swelling pressure exhibited distinct non-linearity, characterized by a delayed response during the early hydration phase followed by a gradual increase to a stable plateau.

To capture these coupled mechanisms, fully coupled THM simulations were performed using the CODE_BRIGHT finite element code (Olivella et al., 1996). The mechanical behavior of unsaturated bentonite was described using the BBM, an elastoplastic constitutive framework treating net stress and matric suction as independent state variables. The numerical formulation explicitly incorporated the Loading-Collapse (LC) yield surface to simulate irreversible volumetric deformation and the coupling between hydraulic hysteresis and mechanical hardening. The simulation results demonstrated excellent agreement with experimental observations, successfully reproducing the spatial propagation of the drying front, moisture redistribution, and the transient evolution of swelling pressure. These findings validate the applicability of suction-dependent elastoplastic frameworks for assessing EBS integrity in high-temperature repository environments.

This work is intended for poster presentation.

1. M.V. Villar, P.L. Martin, F.J. Romero, “Long-term THM tests reports: THM cells for the HE-E test: update of results until February 2014”.

2. S. Olivella, A. Gens, J. Carrera and E.E. Alonso, “Numerical formulation for a simulator (CODE_BRIGHT) for the coupled analysis of saline media 1996”

Speaker



Jusung Park

INH A University

ID 407: Multiphysics Thermo–Hydro–Mechanical Modeling of Frozen Ground Using a Coupled Discrete–Continuum Framework

2:55 PM – 3:15 PM

Author(s): Danyang Tong, ExxonMobil; Giuseppe Buscarnera, Northwestern University; Alessandro Rotta Loria, Northwestern University; David Grégoire, Université de Pau et des Pays de l'Adour (UPPA); Gilles Pijaudier-Cabot, Université de Pau et des Pays de l'Adour (UPPA); Gianluca Cusatis, Northwestern University

Frozen ground in Arctic and high-altitude regions is undergoing significant alteration due to accelerated climate warming. The associated freeze–thaw cycles generate complex thermo–hydro–mechanical (THM) interactions that can compromise the stability and serviceability of critical infrastructure. Understanding these coupled processes requires modeling frameworks capable of representing multiphase behavior, moisture migration, and temperature-driven phase transitions within water-saturated porous media.

This work presents a fully coupled THM formulation that distinguishes between ice formed as a solid phase, which contributes to the stiffness of the porous skeleton, and ice formed as a fluid phase, which exerts internal pore forces. The model is grounded in multiphase poromechanics and incorporates governing equations for mass, momentum, and energy conservation, together with constitutive relations describing permeability evolution, thermal conductivity and freezing–thawing characteristics.

To address mesoscale mechanisms beyond the reach of continuum theory, a complementary discrete THM framework is developed by integrating the Lattice Discrete Particle Model (LDPM) with the Flow Lattice Model (FLM). This coupled explicit–implicit approach enables high-resolution simulation of ice-induced stress redistribution, pore-pressure evolution, and material heterogeneity. The formulations are implemented in ABAQUS using VUEL and UEL subroutines to facilitate two-way coupling between the mechanical and hygrothermal fields.

Verification against benchmark problems, analytical solutions, and literature-based models demonstrates the accuracy and robustness of the approach. Statistical analyses further confirm the ability of the discrete model to capture intrinsic heterogeneity in frozen geomaterials. Numerical simulations across freezing and thawing conditions illustrate the interplay among temperature gradients, ice formation dynamics, and mechanical response.

These developments provide a comprehensive multiscale and multiphysics modeling platform for advancing predictive capabilities related to frozen-ground behavior under evolving environmental conditions.

Speaker



Danyang Tong

Wells Research Engineer | ExxonMobil

MS 009: Energy harvesting and intelligent sensing for sustainable structural health monitoring

2:15 PM – 3:35 PM | Location: KTCH 1B87

Chair(s): Li Ai; Mohsen Amjadi; Jinghao Yang

Moderators



Li Ai

Assistant Professor | University of Texas Rio Grande Valley

ID 239: Flexible, stretchable, and wireless multilayer integrated motion sensor for physical activities monitoring

2:15 PM – 2:35 PM

Author(s): Ruili Zhang, University of Colorado Boulder; Abhrajit Mal, University of Colorado Boulder; Tavis Peterson, University of Colorado Boulder; Jianliang Xiao, University of Colorado Boulder

Real-time and continuous monitoring of motion and vibration is essential for understanding the mechanical response, durability, and performance of engineered systems and human-machine interfaces. Conventional sensing platforms rely on rigid components that introduce mechanical mismatch, stress concentration, and limited strain tolerance, leading to degraded performance under large deformation and cyclic loading. These limitations motivate the development of mechanically compliant sensing systems capable of accommodating complex deformation while preserving stable electromechanical functionality.

Dynamic motion and vibration signatures reflect underlying mechanical loading conditions, kinematics, and system dynamics. However, capturing these responses in soft or highly deformable environments remains challenging due to sensor stiffening effects, interconnect failure, and debonding under repeated strain. Addressing these challenges requires integrated mechanical design strategies that enable strain isolation, stress redistribution, and deformation-tolerant signal transmission.

In this work, we present a flexible, wearable, and wireless multilayer sensing system designed with a focus on mechanical compliance and deformation mechanics. The system employs a soft Ecoflex substrate and encapsulation layer combined with rigid printed circuit board (PCB) functional islands interconnected by eutectic gallium-indium (EGaIn) liquid metal traces. This island-bridge structural architecture confines large strains to the highly deformable liquid metal interconnects while mechanically shielding rigid components from excessive stress. To improve mechanical stability under large deformation, EGaIn is modified with 3 wt% silicon dioxide microparticles, increasing viscosity and suppressing flow-induced instability while retaining high electrical conductivity and stretchability.

Mechanical performance is evaluated through tensile, bending, and cyclic deformation tests, along with real-time motion and vibration measurements under representative dynamic activities, including walking, running, jumping, squatting, and controlled vibration. Results demonstrate stable sensing performance under large elastic deformation and repeated loading. Motion- and vibration-based tests adapted from Parkinson's disease physical examinations are further conducted at the wrist and ankle, illustrating sensitivity to subtle changes in mechanical response.

This work establishes a mechanically compliant, low-power, and wireless sensing platform with broad applicability to wearable monitoring, rehabilitation engineering, and motion- and vibration-based assessment in engineered systems. The proposed design framework provides a foundation for future mechanics-guided optimization and integration with energy harvesting and data-driven analysis for sustainable monitoring systems.

Speaker



Ruili Zhang

University of Colorado Boulder

ID 698: Deep Learning-Enabled Health Monitoring of Wind Turbine Gearboxes Using Vibration and Acoustic Sensing

2:35 PM – 2:55 PM

Author(s): Balavignesh Vemparala Narayana Murthy, Synopsys, Inc.

Gearbox reliability remains a critical challenge limiting the large-scale and sustainable deployment of wind energy systems. Unanticipated gearbox failures result in significant downtime, increased maintenance costs, and reduced energy production, ultimately undermining the resilience and economic viability of renewable energy infrastructure. Reliable, real-time health monitoring is therefore essential for improving operational robustness and extending the service life of wind turbines.

This work presents a comprehensive evaluation of state-of-the-art deep learning architectures for vibration- and acoustic-based health monitoring and fault diagnosis of wind turbine gearboxes. We systematically study residual convolutional neural networks (ResCNNs), bidirectional long short-term memory networks with attention mechanisms (Bi-LSTMs), Transformer-based models, and physics-inspired spectral learning approaches, including Fourier and wavelet neural operators (FNO/WNO). The models are trained and validated using a large in-house experimental dataset comprising 17 representative single-fault conditions—spanning bearing inner and outer race defects, pinion tooth damage, and root cracks across multiple severity levels—as well as realistic multi-fault scenarios that more closely reflect operational wind farm environments.

A unified evaluation framework is employed, combining Bayesian optimization for ResCNN, Bi-LSTM, and Transformer architectures with a detailed sensitivity analysis of WNO hyperparameters, including wavelet basis selection, decomposition depth, and padding strategies. Model performance is quantified using classification accuracy, precision, recall, F1 score, and computational efficiency to assess both diagnostic reliability and suitability for real-time deployment. The results demonstrate near-perfect single-fault classification performance for ResCNN, Bi-LSTM, and Transformer models, with the Bi-LSTM architecture effectively eliminating false negatives. Spectral operator-based models also exhibit strong performance, with FNO and optimized WNO configurations achieving competitive accuracy while offering enhanced interpretability through frequency-domain representations. Importantly, models trained on single-fault data generalize robustly to complex multi-fault cases, underscoring their potential for resilient, real-world condition monitoring.

Beyond fault classification, this work establishes a foundation for future research on data-driven and physics-informed virtual sensing. Ongoing efforts aim to compare generative modeling frameworks—including generative adversarial networks (GANs), diffusion models, and physics-informed AI—to synthesize realistic vibration and acoustic signals across varying operating conditions and fault severities. Such virtual sensing capabilities are expected to address data scarcity, improve model robustness, and support resilience-oriented digital twin frameworks for wind energy systems.

Overall, this study provides practical guidance on neural architecture selection, hyperparameter optimization, and performance-cost trade-offs for trustworthy gearbox health monitoring. By integrating advanced sensing, deep learning, and physics-inspired modeling, the proposed framework contributes to improving the reliability, resilience, and sustainability of modern wind farms. The presentation will highlight key methodological insights, experimental findings, and future directions toward scalable, AI-enabled health monitoring for renewable energy infrastructure.

Speaker



Balavignesh Vemparala

Dr. | Synopsys, Inc.

ID 879: Enhancing Localization Accuracy and Cost Optimization of Acoustic Emission Monitoring in Concrete Using Explainable Machine Learning

2:55 PM – 3:15 PM

Author(s): Kewei Li, Tianjin University; Minzhe Wu, The University of Texas Rio Grande Valley; Li Ai, The University of Texas Rio Grande Valley

Concrete is a fundamental material utilized in the construction of various forms of infrastructure, including bridges and tunnels. Internal defects in concrete, such as cracks and voids, can result in a reduction in load-bearing capacity or even structural failure, which presents a significant risk to public safety. Acoustic emission sensor arrays are instrumental in the identification of internal defects in concrete. However, employing a substantial number of sensors not only enhances the complexity of maintenance but also substantially increases costs. Accordingly, the optimization of the layout and number of sensor arrays has become a pivotal concern. In this study, nine AE feature parameters, including peak amplitude, number of cycles, and duration, were extracted from AE signals collected by sensors at nine fixed positions in a concrete sample. Subsequently, frequency domain spectrum and time-frequency maps were obtained through Fourier transform and short-time Fourier transform, respectively. Four deep learning models were constructed, with the time domain signal, frequency domain spectrum, time-frequency diagram, and AE feature parameters as inputs, respectively. The influence of different sensor channels on the positioning results was analyzed using explainable machine learning methods. The results demonstrated that certain channels had a detrimental impact on defects localization accuracy. By optimizing the sensor combination, localization accuracy can be improved while reducing the number of sensors.

Speaker



Minzhe Wu

PHD student | University of Texas Rio Grande Valley

ID 961: Identifying Physically Consistent Cutoff Frequencies for Accelerometer-Based Vibration Measurements Using Digital Image Correlation

3:15 PM – 3:35 PM

Author(s): Amin Joodaky, Michigan State University; Jiyu Niu, Michigan State University

"Accelerometers are widely used to characterize transportation-induced vibrations; however, measured acceleration signals often contain high-frequency noise that must be attenuated through low-pass filtering prior to numerical integration. The selection of an appropriate cutoff frequency remains challenging, as small variations in cutoff choice can significantly influence the resulting velocity and displacement, particularly under broadband random vibration. While power spectral density (PSD) plots often indicate dominant energy content below approximately 100 Hz, this information alone does not provide a physically grounded criterion for cutoff frequency selection.

This study presents an experimental approach for identifying physically consistent cutoff frequencies by comparing accelerometer-derived displacement with independent displacement measurements obtained using digital image correlation (DIC). A shaker table is excited using random vibration representative of transportation environments. Acceleration signals measured on the shaker are processed using a consistent signal-processing pipeline with varying low-pass cutoff frequencies and numerically integrated to obtain displacement. Simultaneously, shaker displacement is measured using a DIC system, providing a non-contact reference measurement. Cutoff frequencies are evaluated based on quantitative agreement between accelerometer- and DIC-derived displacement responses in both the time and frequency domains.

The results show that cutoff frequency selection has a pronounced effect on integrated displacement and that physically consistent cutoff ranges can be identified through comparison with independently measured motion. The findings provide practical guidance for vibration signal processing in laboratory shaker testing and transportation vibration studies, with relevance to applications such as packaging dynamics and vehicle vibration analysis."

Speaker



Amin Joodaky

Assistant Professor | Michigan State University