Using pavement mechanics to develop pavement materials with less environmental impact
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ASSESSING THE PERFORMANCE OF THE CRUMB RUBBER MODIFIED (CRM) BITUMEN CONTAINING WARM MIX ADDITIVES AT REDUCED AGING TEMPERATURES

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ABSTRACT

The primary objective of the study is to minimise the production temperature and ensure the positive performance of crumb rubber modified (CRM) binder using WMA technology. This study attempts to explore the mixing and compaction temperatures of CRM mixtures incorporated with WMA additives. This study also investigates the effects of two different WM additives, one wax based (Sasobit) and another chemical based (Rediset), on the performance properties of CRM asphalt binder due to reduced aging temperature. To determine the production temperature CRM binders incorporated with WMA technology, the newly developed workability approach has been used in this study. From study, it was found that the conventional equi-viscous method does not yield appropriate results for CRM asphalt binders. Workability analysis showed that CRM mixtures incorporated with WMA technology, regardless of dosage and type, exhibit improved workability at all the test temperatures compared to the CRM mixture without WMA incorporation. It was found that the workability approach used in this study was able to quantify the mixing and compaction temperatures for different CRM mixture incorporated with WMA technologies. About 4-13% and 5-22% reduction in mixing and compaction temperatures, respectively, were obtained for different WMA technologies. To study the impact of reduced produced production temperature on aging, the Fourier transform infrared spectroscopy (FTIR) was conducted on CRM asphalt binders to check changes in their chemical composition due to aging. Performance of the WM modified asphalt binders was assessed using indirect tensile cracking test, (IDEAL CT), dynamic creep test, tensile strength ratio test, and bitumen bond strength (BBS) tests. BBS test was conducted using two types of aggregate Siliceous (Granite) and Calcareous (Dolomite). FTIR analysis showed that the addition of WM additives increases the aging resistance of asphalt binder. Test results revealed that the application of Rediset enhanced the fatigue performance as compared to neat and Sasobit modified asphalt binder. On the other hand, Sasobit improved the rutting performance of the binder, whereas the rutting observed to be similar with the addition of the Rediset. It was found that Rediset acts as an antistripping agent, which aids in improving the bond between asphalt binder and the aggregate, even at reduced production temperatures.

Keywords: Crumb rubber, Warm Mix Asphalt, Workability, IDEAL CT, dynamic creep, BBS.

New challenges in instabilities of shell structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

A NEW XFEM APPROACH FOR THE ANALYSIS OF THIN-WALLED STRUCTURES

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ABSTRACT

Thin-walled beams have many engineering applications. Considering the longitudinal dimension, we propose a new XFEM method with global enrichment functions based upon a coarse 3D solid element mesh. Analytical global enrichment functions are used to provide approximate solution of the beam for deflection as well as for lateral-torsional buckling. To this end we consider vibration modes and buckling modes, including higher order modes. Further, we employ the modification proposed in the stable GFEM approach to obtain a robust numerical behavior.

The resulting model bridges the gap between the Finite Prism Method (FPM), which provides an efficient approximation to beam bending with analytical functions but has also well-known limitations, and a detailed 3D FE model, which can accurately resolve thin-walled structures but is computationally demanding.

The method can be easily extended for beams with non-prismatic cross-sections (e.g., tapered beams) or with perforations, and additionally, one can improve the solution by sectional and/or longitudinal mesh refinements. Moreover, the proposed method enables modelling of different boundary conditions along the beam, such as lateral restraints.

The performance of the model is investigated on several benchmark problems. The results show that the proposed method captures different global and sectional deformation modes including shear-lag and warping of the cross-section, as well as buckling behavior of thin-walled beams subjected to complex loads. Furthermore, convergence studies demonstrate the superior performance of the proposed method as compared to the FPM, and a 3D FE model with a coarse mesh.

Origami/kirigami inspired structures and metamaterials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ENERGY ABSORPTION OF METALLIC KIRIGAMI STRUCTURES

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ABSTRACT

Kirigami, the Japanese art of paper cutting, can be used to generate complex 3D shapes from 2D sheets via out-of-plane buckling. Kirigami structures can also be highly stretchable and accommodate extremely large strains from common materials, such as aluminium, which admit relatively small strains. The high stretchability of Kirigami makes it an ideal method for energy absorption applications.

We investigate the tensile behaviour of metallic Kirigami structures with different geometrical parameters in the parallel-cut pattern. We combine a reduced-order analytical model with a parametric study, using Finite Element Analysis (FEA), to identify the key geometric parameters, such as distance between successive cutting rows, that control the energy absorption behaviour.

Emerging topology and shape optimization techniques in computational design of materials and structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

TOPOLOGY OPTIMIZATION OF ELASTO-PLASTIC STRUCTURES AND MATERIALS

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ABSTRACT

For structures operating within the linear regime, numerical design optimization techniques have proven successful in achieving optimal designs. Simple objectives such as stiffness, eigenfrequency, buckling and peak stress for linear elasticity can now be readily found in commercial finite element software packages. However, less exploration has occurred in the realm of non-linear problems, specifically those involving irreversible material responses and transient loading conditions. In this study, we integrate finite strain viscoplastic and rate-independent plasticity with density-based topology optimization (TO). We assume isotropic hardening and adopt the multiplicative split of the deformation gradient to distinguish between elastic and plastic deformation. To update the design, we employ the gradient-based Method of Moving Asymptotes (MMA), necessitating the calculation of gradients for both cost and constraint functions. Given that the number of design variables (one per element) far exceeds the number of state functions, we opt for the adjoint sensitivity approach. The inherent plastic path-dependence introduces complexity into the sensitivity analysis, leading us to adopt a coupled transient adjoint strategy, effectively transforming it into a terminal value problem. To illustrate our theoretical framework, we design structures and materials optimized for maximum energy absorption and structures that limits the peak plastic work. Our results show that loading rate, loading path, and load magnitude all play important roles in the design of energy-absorbing structures. Furthermore, we will discuss implementation aspects and present results showcasing the successful resolution of large-scale elasto-plastic TO problems.

Topology optimization: From algorithmic developments to applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

INVERSE DESIGN OF MAGNETO-ACTIVE METASURFACES AND ROBOTS: THEORY, COMPUTATION, AND EXPERIMENTAL VALIDATION

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ABSTRACT

Magneto-active structures can undergo rapid and reversible deformations under untethered magnetic fields. The capability to design such structures to achieve programmable shape morphing in three dimensions (3D) under magnetic actuation is highly desirable for many applications. In this work, we develop a multi-physics topology optimization framework for the inverse design of magneto-active metasurfaces that can undergo programmable shape morphing in 3D under external magnetic fields. These metasurfaces remain planar in their initial configurations and are deformed into complex 3D target shapes. The proposed framework accounts for large-deformation kinematics and optimizes both the topologies and magnetization distributions of metasurfaces in conjunction with the directions and magnitudes of the external magnetic fields. We demonstrate the framework in the design of kirigami metasurfaces, bio-inspired robots, and multi-modal magnetic actuators, and the optimized designs show high precision and performance in achieving complex 3D deformations. We also use a hybrid fabrication procedure to manufacture representative designs and conduct experimental tests to validate their programmed 3D deformations, with results showing good agreement with simulation predictions. We envision that the proposed framework could lead to a systematic and versatile approach for the design of magneto-active metasurfaces for robotics applications.

Reference:
[1] Wang, C., Zhao, Z., & Zhang, X. S. (2023). Inverse design of magneto-active metasurfaces and robots: Theory, computation, and experimental validation. Computer Methods in Applied Mechanics and Engineering, 413, 116065.

Recent advances in sensing, SHM, and automated inspections for infrastructure condition assessment: Toward actionable solutions
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DISTRIBUTED STRUCTURAL HEALTH MONITORING OF A FIVE-SPAN BRIDGE

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ABSTRACT

This presentation discusses the structural health monitoring of a five-span concrete box girder bridge in Northern Illinois. The instrumentation involved the installation of distributed fiber optic Brillouin Scattering sensors covering the entire spans of the bridge. Considering that the bridge had a total length of 332 m (1090 feet), approximately 1445 m (4750 feet) of optical fibers were installed to cover and monitor various sections of the bridge. Testing of the bridge involved 15 different load positions over the 5 spans. The load positions were selected based on influence line analysis to create maximum load effects on all the bridge spans. Load tests involved two load steps, with one larger than the other. Loading of the bridge involved using larger commercial trucks with heavy payloads. This presentation will compare the measurements taken three years before the recent measurements pointing at major events causing strain changes in the bridge.

On the mechanics of road and paving materials in the cold, Nordic, and Arctic Regions
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

COMPARISON OF CRITICAL ASSESSMENT METHODOLOGIES AND INDEXES OF LOW TEMPERATURE PERFORMANCE OF ASPHALT BINDERS

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ABSTRACT

In cold regions, one of the most serious distresses in road infrastructure was initiated caused by thermal damage. In particular thermal crackings in asphalt roads since it is commonly used as paving materials. Therefore, accurately evaluating the performance properties of bituminous materials could eliminate or at least mitigate low-temperature cracking, which is of great importance in improving the durability and sustainability of asphalt pavement. The low temperature response of bituminous mixtures mainly depends on the performance properties of the binder itself. The commonly used Bending beam rheometer (BBR) is a prominent low temperature performance evaluation method, which has also been standardized in many regions. However, such a testing method requires a substantial amount of material, moreover, its testing protocol (including cooling medium and thermal history) may underestimate the stiff properties of asphalt binder at low temperatures. In the recent past, a novel method based on the 4-mm parallel-plate geometry Dynamic Shear Rheometer was proposed as an alternative method of BBR. Based on the PG system, the DSR data were converted to equivalent BBR parameters. Plenty of researchers have attempted to correlate the relationships between BBR and 4-mm DSR with available materials, and good indications and correlations have been generated on the predictability of thermal cracking from 4-mm DSR.

In this present study, the Finnish source asphalt binders were applied to validate and assess the proposed correlations. Five methods and indicators together with six long-term aged asphalt binders (four unmodified and two modified binders) were selected for this purpose. First, three temperatures, -12°C, -18°C, and -24°C, were used for the BBR test on all these six asphalt binders, and PG indicators (Tc,s, Tc,m, ΔTc, and PG) were calculated based on the experimental results. Meanwhile, 4-mm DSR tests were conducted on all materials. Next, the related rheological parameters were calculated based on the existing methods, and the PG indicators were computed relying on the correlations. Finally, the DSR computed-based and BBR experimental-based parameters were compared and discussed. However, poor correlations were realized among all five existing methods, no method can be considered as a universal model. This may be attributed to the limited available materials and different testing protocols (sample preparation and thermal history). Therefore, a wider range of materials should be tested to generate a better-correlated model.

Advances in computer vision, deep learning and artificial intelligence for structural health monitoring and inspections
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

OPTIMIZED FILTER DESIGN FRAMEWORK FOR PHASE-BASED VIDEO MOTION ESTIMATION WITH CONTROLLED ERROR DISTRIBUTION

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ABSTRACT

Vision-based motion extraction, known for its non-invasive approach, efficiency, and high spatial resolution, has garnered considerable attention in recent research. This technique, employing camera videos, capitalizes on the capability of pixel sensors to discern 256 or more brightness levels, thereby enabling sub-pixel accuracy in motion estimation. To achieve this, interpolation-based and gradient-based methods have been developed. Phase-based motion estimation, in particular, stands out due to its ability to integrate a broader pixel array, significantly reducing noise sensitivity, and thus has become a key area of research.

Despite its advantages, the accuracy of phase-based motion estimation is heavily dependent on the filter choice and the characteristics of the target object. Employing a standard filter for objects with varied features often leads to inconsistent estimation errors. This issue is especially pronounced in videos containing multiple distinct features and can adversely affect the effectiveness of subsequent response-based analytical techniques. In response to this challenge, we introduce a novel feature-based optimization filter design framework. This framework is tailored to optimize error distribution, with a specific focus on the mean and standard deviation. It utilizes the distinct features of the target region to calculate the error distribution for various filters, enabling the selection of the most optimized filter.

Our framework facilitates the prediction of expected error statistics with enhanced precision, thus improving the accuracy of follow-up response-based analyses. The experimental findings confirm the efficacy of our method in achieving controlled error distribution in motion estimation, which significantly increases the reliability of response-based studies.

Engineering Mechanics Institute Conference and Probabilistic Mechanics & Reliability Conference (EMI/PMC 2024)

Advances in computer vision, deep learning and artificial intelligence for structural health monitoring and inspections
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

PIXEL-LEVEL UNSUPERVISED ANOMALY DETECTION FOR TILE SPALLING IN NOISY STREET VIEW IMAGES

Hai-Wei Wang[1] and Rih-Teng Wu[1]*

[1]*National Taiwan University*

ABSTRACT

The facades of architectural structures frequently undergo surface deterioration, exemplified by tile spalling resulting from the combined effects of aging and environmental conditions. The detachment of such spalled fragments poses significant safety concerns for pedestrians and vehicles on adjacent sidewalks. In recent years, the inspection of exterior walls heavily relies on visual assessments conducted by skilled engineers, a process characterized by its labor-intensive nature and time-consuming requirements. Conventional deep learning methods in this domain often employ a supervised training approach, wherein the model learns representations of spalling and identifies affected areas. However, the supervised approach demands large amounts of labeled data, presenting a challenge in our case due to the lack of spalling images and the variable spallings difficult to label. In this study, we propose an unsupervised learning methodology to alleviate the label-intensive constraints of conventional deep learning approaches. Drawing inspiration from anomaly detection principles, our model is trained on spalling-free building samples, enabling it to learn patterns and data distributions of normal datasets. Consequently, when confronted with a spalling sample, the model identifies anomalous patterns indicative of tile spalling. Furthermore, we have implemented mechanisms in the training process to lower the impact of real-world image noise, such as vegetation or traffic signs, redirecting the model's attention towards the buildings and enhancing overall performance. Our approach relies solely on unlabeled normal data, thus addressing the issue of label-intensity in conventional deep learning methods. This advancement contributes to the efficiency and scalability of spalling detection methodologies, offering an avenue for more label-efficiency inspection processes in the realm of architectural maintenance and safety.

INNOVATIVE LATCHED MASS DAMPER FOR VIBRATION CONTROL INSPIRED BY WAVE ENERGY CONVERTER

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[1]The Hong Kong Polytechnic University

ABSTRACT

Traditional passive dampers are sensitive to frequency modulation and difficult to achieve ultra-low frequency modulation. Ultra-low frequency vibrations are common such as vibrations of super-high buildings and floating energy infrastructures. Latching control is a phase optimization method applied in wave energy converters (WECs). Inspired by the latching control of WEC, this paper proposed the latched mass damper (LMD) and three different control strategies for ultra-low frequency vibration control. The LMD can directly extend the periods to match well with the long-period (low frequency) vibrations by introducing the latching forces. First, the theoretical model of WEC and LMD is established and analyzed. Then, the dynamic performances of LMDs with different strategies are compared. Next, the feasibility of latching control in LMD is verified by a proof-of-concept experiment. Furthermore, a case study is carried out based on the 76-story building subject to the across-wind loads benchmark model. The results indicate that the proposed LMD and strategies for vibration control are feasible. The proposed latching control mechanism and strategies can provide an innovative solution for improving the efficiency of high-frequency detuned dampers, designing of long-period dampers with limited stroke spaces, and adaptive semi-active dampers in the future.

Natural hazard assessment with monitoring, modeling, and uncertainty quantification
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

A PROBABILISTIC ASSESSMENT OF THE LIQUEFACTION POTENTIAL EVALUATION BY CONSIDERING SPATIAL VARIABILITIES OF GEOLOGICAL AND GEO-PROPERTY MODELS

Wan-Ying Chien[1], Yu-Chen Lu[1], Hui Wang[2], Jia-Jyun Dong[1] and C. Hsein Juang[1]*

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ABSTRACT

Earthquake-induced soil liquefaction can cause enormous life and economic losses. The liquefaction potential map plays a significant role in liquefaction hazard assessment, control, and mitigation, as it can be used to visualize the risk and facilitate easy and effective communication among different stakeholders. Most traditional regional liquefaction potential maps are interpolated from the evaluated liquefaction potential index (PL) at each borehole, which renders the deterministic liquefaction hazard level but seldom takes the spatial variabilities of geological configuration and geo-property into consideration. However, these spatial variabilities may bring doubts about the accuracy and applicability of the traditional regional liquefaction map.

To account for the uncertainties that exist in the geological and geo-property models, this paper presents a probabilistic assessment framework of the liquefaction potential evaluation by considering both uncertainty sources. A case history in the Taipei Basin, Taiwan is selected as the demonstrated example. Dozens of SPT borehole logs were collected at this site. First, the 3D coupled geological and geo-property random field method is adopted to simulate a series of geological models and their derived geo-property (normalized SPT-N, N1,60cs) models. Then, a series of spatial distributions of the safety factor against liquefaction (FL) were obtained by substituting the geological and geo-property models into the simplified method. Finally, the mean, uncertainty, and confidence interval of PL could be further calculated based on the FL models. Additionally, this paper establishes the quantified correlation between the geo-property model uncertainty and the PL uncertainty. A liquefaction potential (FL) map with improved reliability and confidence level by considering spatial variabilities of geological and geo-property models is provided.

Mechanics of granular materials: Modeling and characterization
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EFFICIENT MODELING APPROACHES FOR LATTICE DISCRETE PARTICLE MODELS

Jiajia Wang[1], Jan Vorel[2], Wouter Botte[1] and Roman Wan-Wendner[1]*

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[2]Czech Technical University in Prague

ABSTRACT

Reliable and computationally efficient models are essential in the design, optimization, or control for various application domains. However, simulating the mechanics of granular materials often becomes impractical in terms of computational cost. Finding convenient trade-offs between the accuracy and calculation time of such computational models is a prominent research focus. This paper employs a state-of-the-art Lattice Discrete Particle Modeling (LDPM) to simulate concrete at the coarse aggregate level, streamlining the number of tessellation facets attached to the edges. Whereas the original formulation of LDPM involves 12 Facets for each basic four-particle tetrahedron, this study introduces a simplified discretization approach for LDPM, incorporating either 6 Facets and Edge-based interactions or 12 Facets and Edge-based interactions. The goal is to significantly reduce computational costs while maintaining accurate predictions of concrete fracture behavior. Uniaxial compression and three-point bending mechanical models are employed for simulations, exploring various combinations of 6 Facets and Edge-based interactions or 12 Facets and Edge-based interactions. Mechanical behaviors and computational costs are obtained for different combinations, and statistical analysis is performed to identify the most efficient and accurate model. The results indicate that modeling approaches incorporating Edge-based, 6 Facets and 12 Facets interactions substantially reduce computational costs, providing similar results in terms of structural response as the original LDPM based on 12 Facets. This research paves the way for advancing the utilization of LDPM in concrete mechanics simulations.

Plan the future: Innovations in advanced cementitious materials and sustainability
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

UNLOCK CO2 SEQUESTRATION POTENTIAL OF CONCRETE THROUGH A BIOMOLECULE-REGULATED CARBONATION PROCESS

Xiaodong Wang[1] and Jialai Wang[1]*

[1]The University of Alabama

ABSTRACT

Concrete with ordinary Portland cement (OPC) as the main binder is the most widely used construction material in the world. On one hand, the production of OPC is highly energy-intensive and responsible for approximately 8% of global CO2 emissions. On the other hand, the massive volume of concrete used in construction each year offers one of the largest sinks for CO2 through a mineral carbonation process. However, existing technologies can only sequestrate very small amount of CO2 due to the inherited limitation of the existing carbonation methods. The major objective of this study is to increase the amount of CO2 sequestrated in concretes by at least one order of magnitude higher than existing technologies and drastically increase the compressive strength of the produced concrete. To this end, a new pathway to sequester CO2 in concrete is proposed through a biomolecule regulated carbonation (BioCarb) method. In this method, cement slurry is first carbonated through bubbling CO2 under the regulation of some biomolecule. The biomolecule functions as a chelating agent to facilitate the carbonation of the cement slurry, a hydration suppressor to allow more complete carbonation, and a dispersant and polymorph controller of the produced CaCO3 to disperse metastable CaCO3 nanoparticles produced in-situ by the carbonation. The resulting carbonated slurry is then mixed with other ingredients to make concrete. Testing results suggest that this method can store at least 15lb-CO2 in one cubic yard of concrete, which is 30 times more than existing technology. More importantly, the compressive strength of the concrete can be enhanced over 20%, drastically reducing the CO2 emission of the produced concrete.

NOVEL PHASE CHANGE MATERIAL MICROCAPSULE FEATURING AN INORGANIC SHELL AND A BIO-INSPIRED SILICA COATING FOR STRUCTURAL CEMENTITIOUS MATERIALS

Abdulmalik Ismail[1] *and Jialai Wang**[1]

[1]*The University of Alabama*

ABSTRACT

Phase change material (PCM) microcapsules offer a promising approach for integrating PCM into building materials for efficient thermal energy storage. This study presents the development of a novel PCM microcapsule specifically designed for incorporation into cementitious materials. The microcapsule consists of a low-cost PCM core derived from vegetable oil by-products and a durable inorganic shell made from cenosphere, a hollow fly ash generated from coal burning power plants. A novel process is developed to apply a silica coating to these cenosphere-based PCM microcapsules (CPCM), resulting in bioinspired-silica-coated CPCM microcapsules (BCPCM). This coating process draws inspiration from marine microorganism-based silica production and utilizes low-cost sodium silicate as a precursor, enabling eco-friendly and cost-effective manufacturing at ambient temperature and mild pH conditions. The morphology, chemical stability, and thermal properties of the BCPCM along with its thermo-mechanical performance in cementitious composites were comprehensively analyzed. Experimental results demonstrate successful silica deposition on BCPCM, leading to enhanced latent heat properties of the produced BCPCM. With the silica coating, BCPCM exhibits a 50°C delay in thermal decomposition compared to CPCM, enhancing fire resistance and preventing premature PCM leakage of the microcapsule. The bioinspired silica coating effectively restores over 10% of the strength loss for each percent increase in CPCM incorporated into the mortar. The thermal performance experiments reveal that increasing the BCPCM content reduces temperature peaks and rates of temperature increase, indicating an improved capacity for thermal energy storage. This new PCM microcapsule provides a cost-effective solution to integrate thermal energy storage to cementitious material, as evidenced by that over 30% aggregates (in volume) can be replaced by the microcapsule without drastically loss of strength.

Plan the future: Innovations in advanced cementitious materials and sustainability
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

BIO-INSPIRED SILICA COATING FOR STEEL FIBERS

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[1]The University of Alabama

ABSTRACT

Concretes are most used construction materials. They can be considered as a three-phase material, the cement matrix, reinforcements and interfacial transition zones (ITZ) between the cement matrix and reinforcements. Various materials have been used as reinforcements for concretes, including coarse/fine aggregates and various fibers (steel, glass, carbon, polymers, natural fibers). The ITZ plays a critical role on the mechanical properties and durability of the concrete. This invention proposes a low-cost, eco-friendly, bio-inspired method to coat a thin layer of silica on the surface of steel fibers so that the bond strength between the fibers and the cement paste can be significantly improved, leading to higher strength and durability of the produced concrete.

Plan the future: Innovations in advanced cementitious materials and sustainability
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ENHANCED INTERNAL CURING FOR UHPC USING CARBAMIDE SOLUTION CARRIED BY PERFORATED CENOSPHERES

Jialai Wang[1]

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ABSTRACT

This paper proposes an internal carbon-mineralization method, using carbamide solution carried by perforated cenospheres (PCs), to produce a synergistic curing effect for UHPC based on internal curing, where PCs was added as an alternative to part of the fly ash of UHPC. Experimental investigations show that the addition of PCs with carbamide solution concentrations ranging from 0.5% to 3.0% sustained the internal relative humidity at high levels, effectively mitigated the autogenous shrinkage, and slightly enhanced the 28d compressive strength of the produced UHPC. Very small amount of the carried carbamide solution by PCs was released through the dynamic and vigorous mixing processes of UHPC, while most of it was released due to the changes in the internal relative humidity of UHPC. As a result, the presence of carbamide in the hydrating system of UHPC consumed partial hydrated Ca(OH)2 for internal carbon-mineralization. The produced fine CaCO3 can thus densified the microstructure and strengthened the micro-mechanical properties of UHPC, along with internal curing effect. A comparison analysis of PCs for internal carbon-mineralization with other water reservoirs for internal curing for UHPC demonstrated the features of PCs of high-efficiency and positive role in enhancing the performance of UHPC. Moreover, the mechanism of internal carbon-mineralization was discussed and revealed.

Failure and function in structural stability applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

BUCKLING ANALYSIS OF MWCNT AND FUNCTIONALLY GRADED CARBON NANOTUBE REINFORCED COMPOSITE QUADRILATERAL PLATE

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[2]City University of Hong Kong

ABSTRACT

The structural instability of multi-walled carbon nanotubes (MWCNTs) has captured extensive attention due to the unique characteristic of extremely thin hollow cylinder structure. This presentation firstly investigates the axial buckling behavior of MWCNTs with the length-to-outermost radius ratio less than 20 within the framework of the Donnell shell theory. Subsequently, from nanoscale extending to macroscale structures of functionally graded CNT reinforced composite plates (FG-CNTRC), the thermal vibration and buckling of FG-CNTRC quadrilateral plate are considered including four distributions of reinforcements along the thickness direction: uniform distributions (UD), FG-V, FG-O and FG-X. The corresponding effective material properties including Young's modulus, mass density, Poisson's ratio and thermal expansion coefficients are estimated by the rule of mixture with respect to the CNT efficiency parameters based on the size-dependence principle. The first-order shear deformation theory (FSDT) considering thermal effects is employed. Based on Hamilton's principle and moving least square (MLS) approximation, the discrete governing equations for the vibration of FG-CNTRC plate are derived. The free vibration of regular and irregular plates with and without the temperature effect are considered, and the corresponding natural frequencies and mode shapes are obtained as an eigenvalue problem. The stability analysis of uniaxial and biaxial mechanical and thermal buckling is also conducted. Finally, the effects of volume fraction, distribution pattern, geometrical characteristics and temperature on the buckling behavior of CNTRC quadrilateral plate are discussed in detail.

Advances in modeling wind and its effects on the built environment
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

APPLICATION OF AN IMMERSED BOUNDARY METHOD TO GENERATE BOUNDARY LAYER TURBULENCE AND NON-UNIFORM WIND FIELDS

Jianyu Wang[1] and Catherine Gorlé[1]*

[1]Stanford University

ABSTRACT

Large-eddy simulations of wind engineering problems frequently rely on a combination of artificial turbulence generation and a rough wall function on the ground surface to generate a neutral surface layer flow. This approach may fall short when the aim is to capture non-standard wind conditions. Examples range from modeling the roughness sublayer for simulations of low-rise buildings to modeling profiles that deviate from the typical log-law shape or modeling unsteady events such as downbursts. To address these challenges, this study explores the use of an Immersed Boundary Method (IBM) to simulate the interaction between the wind flow and a combination of roughness elements, spires, or louvers positioned in the flow development section of the computational domain. Similar to wind tunnel experiments, the upstream configuration of these elements can then be optimized to reproduce a specific target wind field in the test section of the domain. We employ a direct forcing IBM, implemented in an otherwise body-fitted computational fluid dynamics (CFD) code. The implementation is tested on two set-ups: one with roughness elements that will generate a roughness sublayer for low rise building applications, and one with louvres that generate a non-standard mean velocity profile. For both cases, the IBM flow predictions in the test section downstream of the flow development section are compared against results obtained using body-fitted meshes for the same configurations. For the cases where data is available, comparative analysis with wind tunnel experiments is used to further determine the method’s capability to accurately simulate a range of ABL wind conditions. The findings demonstrate the method’s promising capabilities for simulating boundary layer flows with a range of mean velocity profiles and turbulence characteristics, simplifying the set-up of numerical analysis of a wide range of wind engineering flows without compromising on computational efficiency.

Recent advances in sensing, SHM, and automated inspections for infrastructure condition assessment: Toward actionable solutions
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EXPERIMENTAL CHARACTERIZATION AND COMPUTER VISION-BASED DETECTION OF PITTING CORROSION ON STAINLESS STEEL

Long Wang[1], Luke Yium[1], Duncan Fure[1], Christopher Chau[1] and Jessica Luu[1]*

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ABSTRACT

Pitting corrosion is a prevalent form of corrosive damage that can weaken, damage, and initiate failure in corrosion-resistant metallic materials. For instance, 304 stainless steel is commonly utilized in various structures (e.g., miter gates, heat exchangers, and storage tanks), but is prone to failure through pitting corrosion and stress corrosion cracking under mechanical loading, regardless of its high corrosion resistance. On a microscopic scale, pitting corrosion occurs when an anion with high permeability (typically chloride) passes through the passivating oxide layer on the exterior of stainless steel. Once implanted, the ions will concentrate on local anodic regions and bore holes into the bulk material, depositing byproducts around cathodic regions. The pit growth typically follows a sigmoidal trend with an initial high growth rate during nucleation, followed by an eventual saturation limit, which will ultimately lead to material failure. Evidently, pitting corrosion damage can significantly compromise structural safety and reliability. However, current techniques for evaluating and detecting pitting corrosion (e.g., visual inspection, profilometry, metal penetration, and eddy currents) are still relatively limited and ineffective. Therefore, in this study, to better understand the pitting corrosion damage development under different conditions, accelerated corrosion experiments were designed to generate pits on 304 stainless steel specimens with and without mechanical loading in a consistent and controllable manner. The pit morphology (i.e., depth and surface opening area) development over time was characterized using a laser scanning system. Image processing techniques were used to characterize the statistical features of pit size and spatial distribution based on optical images of corroded specimens. In addition, to achieve scalable and non-destructive assessment of pitting corrosion conditions, convolutional neural network-based computer vision algorithms were adopted and implemented for identifying the existence of pit damage on the steel specimens. Overall, this study contributes a novel experimental technique of high controllability for generating pitting corrosion damage with and without mechanical loading, previously unavailable data on pit morphology evolution under different conditions, and computer vision algorithms for efficiently detecting pit damage on structural members.

Structural reliability, bridges, and truck loads
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

LONGITUDINAL MULTIPLE PRESENCE OF TRUCKS ON CONTINUOUS BRIDGE SPANS

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ABSTRACT

Truck load has a major impact on the safety and service performance of highway bridges. In design and evaluation, multiple trucks simultaneously present on the same bridge forms the controlling load case. The magnitude of these controlling load cases depends on various factors such as truck weight and configuration, average daily truck traffic, bridge span length, and number of lanes. Current AASHTO LRFD and LRFR provisions provide guidelines on quantifying the multiple presence of trucks in conjunction with standard truck weight and configuration. However, the quantification is uncultivated, and yields nonuniform bridge safety. This presentation focuses on the multiple presence of trucks loading in the same lane(s) of continuous span bridges. Trucks' longitudinal multiple presence behavior was studied through an unprecedentedly large number of high-quality weigh-in-motion data gathered in eight states across the US. A new approach to analyzing trucks in platoons was developed. The results suggest lower longitudinal multiple presence factors for highway bridge evaluation and design for a more-uniform structural safety and performance.

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Advances in modeling wind and its effects on the built environment
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EVALUATION OF RANS MODELING OF URBAN WIND AND TEMPERATURE FIELDS USING OPENFOAM FOR UNCERTAINTY QUANTIFICATION

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ABSTRACT

OpenFOAM underpinsthe foundational numerical framework for the Urban Environmental SMART Sustainable Solutions’ (UES3) street-scale numerical modeling component of Community Research on Climate and Urban Science(CROCUS). Associated developments seek to resolve urban form, urban fabric, and urban functionality at high resolution, the final goal being to serve as a digital twin for the City of Chicago. To this end, meter-scale computational fluid dynamics simulations are being performed with multi-physics support using downscaled mesoscale simulation datasets for real-case comparisons, thus melding simulations and observations at the street level. Dynamical Processes are modeled using Reynolds-averaged (i.e. RANS) variables through different turbulent parameterizations, and the results are evaluated against both large eddy simulations (LES) and field measurements conducted for CROCUS measurement sites. RANS simulations are performed with larger time steps and permit coarser grids than LES, and considers both the variable mean and its second-order moments, which allow evaluation of model performance and forecast uncertainties with much cheaper computational costs compared to LES. In the study afoot, uncertainties are evaluated by comparing RANS results with LES ensemble results and field measurements. Inverse modeling of mean fields is also attempted.

Resilience of coastal structures, systems, and community subjected to hazards
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EFFECTS OF WALL INCLINATION ON ELEVATED STRUCTURES SUBJECT TO BREAKING WAVES: A MULTIPHASE SPH NUMERICAL EXPLORATION

Krisna Pawitan[1], Maria Garlock[1] and Shengzhe Wang[2]*

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ABSTRACT

Due to the increasing probability of extreme weather events, future coastal structures will need to endure higher waves and sea levels, and also short-duration impact pressures from breaking waves. These impact forces can be 10 to 50 times greater than nonbreaking waves and may result in structural failure. The complicated interaction between water and air during wave breaking makes such phenomena difficult to explore numerically and often relies on experiments, which can be expensive, time consuming, and challenged by scaling laws. Meshless smoothed-particle hydrodynamics (SPH) can overcome traditional numerical and experimental difficulties in modeling breaking waves. Unlike traditional Eulerian methods, in SPH fluids are modeled as particles with their trajectory calculated via the discretized Navier-Stokes equations using a kernel function. SPH is therefore well suited for highly nonlinear and deformable flows where air and water interactions at the free surface can be simulated without special treatment.

In this research, we explore the influence of front wall inclination on the pressures and forces induced by wave breaking on an elevated structure. Multiphase (water-air) SPH was used to examine a typical two-story building 6 m high and 10 m long with three different frontal wall inclinations (positive/negative 15 degrees and vertical) impinged by a single breaking wave propagating landwards (left-to-right). Four different levels of building elevation were considered: (1) on-grade (bottom of structure in contact with the ground), (2) semi-submerged (negative air gap), (3) still water level (zero air gap), and (4) fully elevated (positive air gap). Results show that relative to a vertical surface, both positive (clockwise) and negative (counterclockwise) front wall inclinations altered breaking wave pressures depending on the structure's position relative to the still-water level (SWL). When the bottom of the structure is located below the SWL, positive inclination decreased breaking wave loads by up to 21percent, while a negative inclination may result in 50 percent higher pressure maxima. However, for a structure elevated above the SWL (positive air gap), negative and positive inclinations witnessed reductions to the pressure maxima of 35 percent and 10 percent, respectively, when compared with a vertical surface [1].

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SOURCE LOCALIZATION WITH 1D METAMATERIAL ARRAYS FOR ACOUSTIC APPLICATIONS

Weidi Wang[1], Shayan Razi[2], Arghavan Louhghalam[1], Mazdak Tootkaboni[2] and Alireza Amirkhizi[1]*

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ABSTRACT

This work aims to develop novel approaches for acoustic source localization using mechanical metamaterials and their rich dynamic behaviors. Exploiting the dispersion characteristics of metamaterials allows for selective activation of vibrational modes in response to a predefined range of incident wave angles. A 1D finite-sized metamaterial array embedded in water environment is designed as the sensor material and analyzed through the acoustic-solid multi-physics setup. The local resonance modes create multiple so-called optical branches in the eigenfrequency band. These resonance modes can be accessed and activated when the oblique incident wave possesses a certain combination of frequency and wavevector, thereby providing angle-selective behavior near these points in the frequency-wavevector parameter space, unlike the plain spatially harmonic responses provided by traditional homogeneous materials. The scattering response of this periodic metamaterial is then evaluated by a frequency domain calculation with a plane incident wave from varying angles. Using the eigen-modes of the micro-structure as the signal processing kernel, a beamformer model is trained, whose output is shown to be maximized only when the incident angle shares the same wavevector component with the eigen-mode at the operating frequency. Additionally, the sidelobe levels are substantially suppressed. Such an approach shows strong potential for enhanced angle detection, and has expanded application reach of design optimization with phononic crystals and low frequency locally resonant metamaterials.

CLASS FRAGILITY MODELS OF TRANSMISSION TOWERS FOR REGIONAL ANALYSIS OF TRANSMISSION SYSTEMS UNDER HURRICANES

Xinyue Wang[1] and Paolo Bocchini[1]*

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ABSTRACT

Power transmission systems constitute interconnected networks that cover very large regions and are vulnerable to natural hazards, hurricanes in particular. Lattice steel towers (also known as transmission towers) are commonly used as the support structures in transmission lines and are prone to damages under strong winds. For regional risk and resilience analysis of transmission systems under hurricanes, class fragility models that account for the structure-to-structure uncertainties inherent to a portfolio of transmission towers (in addition to the load uncertainties and within-structure uncertainties) are urgently needed. To fill this gap, this study presents the development of class fragility models for transmission towers by addressing three major challenges.

First, a classification scheme for transmission line support structures is proposed, using structural characteristics (instead of electrical characteristics) that are suitable for the purpose of structural fragility analysis. Second, key design parameters (such as span length) that cause the structure-to-structure variability are identified and are used to characterize the structure-to-structure uncertainties within the interested portfolio of transmission towers. Third, physics-based surrogate models of panel components are developed, which not only facilitates the modeling and analysis of portfolios of transmission towers but also simplifies the uncertainty treatment by condensing modelling parameters. The methodology is demonstrated using the Florida transmission line inventory, where the class fragility models are derived with propagating all three sources of uncertainties. Moreover, a comprehensive sensitivity study is conducted to investigate the significance of the various sources of uncertainties.

AI-enhanced probabilistic reliability assessment
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EXPLORING THE MICROTEXTURE-EFFECTIVE PROPERTY RELATIONSHIP VIA A MACHINE-LEARNING ASSISTED DATA-DRIVEN APPROACH

Xuejing Wang[1], Arghavan Louhghalam[2] and Mazdak Tootkanoni[3]*

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ABSTRACT

The exploration and advancement of fracture-resistant materials hold substantial implications for various engineering disciplines, such as civil, mechanical, aerospace, and others. This presentation introduces a model designed to simulate fracture behavior in heterogeneous materials using an innovative hybrid energy-based approach. The methodology incorporates the potential-of-mean-force (PMF) formulation of the lattice element method (LEM) and directly applies Griffith's fracture criteria [1]. The subsequent application of this approach involves assessing the macroscopic response of random porous materials under external loading. Through a statistical analysis of numerous realizations of two-phase porous materials, we establish a correlation between microstructural properties and macroscopic response. This involves defining and exploring a diverse set of geometric descriptors that characterize micro-texture, including porosity and its local variability, modes of autocorrelation functions in random media, and various graph-theoretical features describing the connectivity of the pore network. With a focus on Bayesian machine learning techniques, particularly Bayesian Additive Regression Tree (BART), we leverage these methods to develop predictive tools for the macroscopic response of porous materials. Furthermore, our study places special emphasis on feature selection through BART to identify the key dominant features significantly impacting the elastic and fracture properties of the materials under investigation. This enables an effective prediction of material performance with reduced computational demands.

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Meshfree, peridynamic, and particle methods: Advancements and applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

N-ADAPTIVITY: A NEURAL NETWORK ENRICHED PARTITION OF UNITY FOR SOLVING BOUNDARY VALUE PROBLEMS BASED ON POTENTIAL ENERGY MINIMIZATION

Jonghyuk Baek[1]*, Yanran Wang**[2] *and Jiun-Shyan Chen*[2]

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ABSTRACT

This study introduces a novel neural network-enriched Partition of Unity (NN-PU) approach for solving boundary value problems. Motivated by NN-RKPM [1, 2], this NN-PU method employs neural network (NN) enrichment functions, driven by NN-based potential energy minimizations, as extrinsic bases to the background approximations under the Partition of Unity (PU). The local feature characteristics are discovered by NN blocks at the offline stage, forming the NN basis functions. The feature-encoded block-level neural networks are designed to increase sparsity and interpretability of the NN architecture. At the online computation of problems with similar features, each pre-trained feature-encoded NN sub-block targets a distinct local feature as the enrichment of the background PU approximation. The proposed NN-PU approximation and feature-encoded transfer learning forms a model adaptivity framework, termed the neural-refinement (n-refinement). Demonstrated by solving various elasticity problems, the proposed method offers accurate solutions while notably reducing computational resources compared to conventional h- and p-adaptive refinements in the mesh-based methods.

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Engineering Mechanics Institute Conference and Probabilistic Mechanics & Reliability Conference (EMI/PMC 2024)

Geometries & design: Opportunities for sustainable construction
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

INCLUSIONS GOVERN THE MECHANICAL DEVELOPMENT OF CEMENTITIOUS MATERIALS

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ABSTRACT

In order to address the issue of global warming caused by carbon emissions, various industrial wastes have gained wide popularity in the construction materials market due to active pozzolanic and superior physical properties. However, significant shrinkage and slow strength development render the interface between rock particles and the mortar matrix vulnerable to delamination, ultimately imposing an adverse effect on the development of mechanical properties of cementitious materials. To enable the incorporation of alternative cements and aggregates in concrete, this study calculated the stress distributions caused by mortar shrinkages and identified delamination between rock particle and mortar matrix based on Drucker-Prager failure criterion. Further, a systemic experimental study was carried out to observe the length changes in different cementitious mortars during the early hydration period. Ultimate compressive and tensile strength tests were conducted on cylinder samples after 28 days, which not only offered insights into the mechanical performances of various cement-based materials, but also provided crucial inputs for the proposed theoretical model. A parameter sensitivity study was implemented to explore the effects of rock fractions and particle sizes on delamination occurrences. The results offer valuable suggestions for designing key material and geometric parameters that exhibit a crucial role in controlling the mechanical performance development of concrete materials.

4M (modeling of multiphysics-multiscale-multifunctional) engineering materials and structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MODELLING OF CONCRETE SHRINKAGE AT MESOSCALE IN A MULTI-PHYSICS FRAMEWORK

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ABSTRACT

The durability and long-term performance of concrete structures are intrinsically linked to their resistance against shrinkage-induced effects. Drying processes in cement-based composites create moisture gradients, leading to non-uniform shrinkage and surface cracks. Studying this intricate mechanical behavior under diverse environmental conditions demands numerous investigations, ideally suited for numerical analysis. This study introduces a mesoscale Multi-physics Lattice Discrete Particle Modeling (M-LDPM) simulation framework to investigate the shrinkage behavior of concrete. The coarse aggregates can be simulated in discrete particles within the volume of concrete randomly by LDPM, to capture the geometrical definition of the concrete meso-structure. In this presentation a new formulation is proposed to distinguish the behavior of non-reactive aggregates from reactive mortar. Another component within M-LDPM is the Hygro-Thermal-Chemical (HTC) model, which plays a vital role in characterizing ongoing curing processes and accounting for heat- and moisture-induced eigenstrains of the reactive mortar. Calibration and validation of the numerical model rely on a series of concrete shrinkage experimental datasets from the existing literature. The results show an excellent agreement between numerical predictions and experimental data, demonstrating significant enhancements in spatial variability and crack formation compared to simpler formulations without increased computational burden. This simulation framework offers a powerful tool to examine the long-term mechanical behavior of concrete structures under diverse environmental conditions, offering valuable insights for improving durability and design considerations.

SINUSOIDAL HELICOIDAL ARCHITECTURE WITH NONPLANAR LAYERING OF FILAMENTS IN ADDITIVELY MANUFACTURED CEMENTITIOUS MATERIALS

Yu Wang[1], Ala Douba[1], Jan Olek[1], Jeffrey Youngblood[1] and Pablo Zavattier[1]*

[1]Purdue University

ABSTRACT

The adoption of additive manufacturing of cementitious materials empowered the flexible shaping of external forms and the internal architecture of structural elements. The application of internal filament architectures enables the production of structural elements with unique and tailorable mechanical properties. An effective strategy for designing architectured cement-based materials involves drawing inspiration from nature, particularly biological composites celebrated for their exceptional attributes of high impact resistance and damage tolerance. The sinusoidal helicoidal architecture found in the dactyl club of the mantis shrimp stands out as a notable example of bio-inspired design. During predatory interactions, the impact region of the mantis shrimp's dactyl club, equipped with a unique sinusoidal helicoidal architecture, demonstrated exceptional resistance to extremely high compressive stresses, effectively withstanding the intense forces generated during shell-breaking actions. This presentation will cover the development of 3D-printed concrete (3DCP) specimens featuring nonplanar layering of filaments and sinusoidal helicoidal architectures aimed at improving the mechanical performance of 3DP concrete under compressive loading. The approach to developing the nonplanar layering of filaments in 3D printed concrete will be highlighted, and the influence of this novel architecture on selected mechanical properties of 3D-printed concrete specimens will be discussed.

Discrete models for the simulation of infrastructure materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

A DUAL RANDOM LATTICE MODEL FOR THE SIMULATION OF THE TIME EVOLUTION OF BACKWARD EROSION PIPING

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ABSTRACT

Backward erosion piping (BEP) has long been recognized as a significant factor contributing to failures in geotechnical flood protection infrastructure. Despite its relevance, the lack of numerical models for the simulation of the phenomenon has hindered comprehensive understanding and accurate predictions of this highly localized and temporally dynamic phenomenon. This study introduces a novel Dual Random Lattice Modeling (DRLM) framework designed for three-dimensional simulations of BEP, with particular attention devoted to its temporal evolution. The framework incorporates two key innovations: (1) a novel flow energy-based constitutive relationship for time-dependent soil erosion based on the theory of rate processes (Wang et al., 2024), and (2) an algorithm for calculating coupled erosion-induced degradation on dual lattices, ensuring accurate computation of the 3-D hydraulic gradient field. Differently from available semi-analytical approaches, the proposed erosion law is grounded in fundamental granular physics, enhancing its applicability across diverse soil conditions. Moreover, the discrete and spatially random nature of DRLM makes it well-suited for simulating highly localized processes like BEP (Fascetti & Oskay, 2019). The framework's capabilities are evaluated through comparisons with experimental observations (Robbins et al., 2018), demonstrating good agreement in topological distribution of erosion paths, pipe progression velocity, and evolution of local gradients. The DRLM approach is proven to be the first framework capable of simultaneously capturing the three-fold features essential for accurate BEP simulation in geotechnical infrastructure.

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Uncertainty characterization and propagation in complex nonlinear structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

NON-PARAMETRIC DIRECTIONAL ENVIRONMENTAL CONTOURS: A METHOD FOR ESTIMATING BRIDGE DESIGN LOAD COMBINATIONS OF WIND AND TEMPERATURE

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ABSTRACT

In recent times, there has been a notable surge in the construction of super-span cable-supported bridges. The continuous growth of the bridge span significantly increases the proportion of environmental load effects within the overall effects. Reassessing the design wind and temperature load combinations from a reliability perspective is essential to guarantee the structural safety of super-span bridges. The environmental contour (EC) method is a representative inverse reliability technique for estimating design loads linked to a given reliability index for engineering structures. An EC defines a set of all possible design points to be explored to find the maximum structural response associated with a target exceedance probability. The point on the EC with the extreme response determines the design environmental load combination.

In accordance with the principles of the EC method, this study introduced a non-parametric directional environmental contour method (NP-DECM). The NP-DECM was designed to find the directional environmental load combination (here, it refers to the wind and temperature loads) associated with the target reliability for the design of super-span bridges. Using the inverse Rosenblatt transformation, the directional ECs were constructed by mapping the points on ECs from the standard normal space to the true physical space based on the joint probability distribution (JPD) of the environmental variables. Notably, the JPD for wind direction, wind speed, and temperature adheres to a circular-linear-linear configuration, given the circular nature of the wind direction variable [1]. Two non-parametric methods were proposed to obtain the aforementioned JPD: the kernel density estimation-based model and the Bernstein copula-based model. A comprehensive evaluation of the proposed approach was conducted through a case study of the Changtai Yangtze River Bridge, a cable-stayed bridge with the largest main span of 1176 m in the world. Through this case study, the design wind and temperature load combinations were determined, with a specific emphasis on different wind directions. The results revealed substantial variations in the load combinations, underscoring the significance of accounting for diverse wind directions in the design process.

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STRUCTURAL DAMAGE DETECTION USING PHYSICS-INFORMED DOMAIN ADAPTATION

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ABSTRACT

Structural damage detection is a crucial aspect of structural health monitoring. Unsupervised anomaly detection can predict the structure's state as either healthy or damaged, but it may face challenges in damage localization. In contrast, supervised damage detection can localize the damage when the damage diagnosis model is trained with the data from a finite element model (FEM) that can accurately represent the actual structure. However, mismatches between the FEM and the actual structure are inevitable due to modeling errors, real-world uncertainties, and operational conditions. Consequently, the damage diagnosis model trained on the FEM cannot be tested on the actual structure, given the discrepancy in training and testing data distributions. To address this, unsupervised domain adaptation, a subset of transfer learning, transfers knowledge from a source domain (i.e., FEM) to a related target domain (i.e., actual structure). Existing domain adaptation methods demand a large amount of unlabeled data from the target structure under both healthy and damaged states to train the damage diagnosis model, which is impractical. Physics-informed neural network (PINN) integrates physical laws governing a given dataset, reducing the number of training samples needed from the target domain. In this work, domain adaptation with adversarial training is employed to ensure that the extracted features from source and target domains maintain a similar data distribution. Moreover, PINN is incorporated into domain adaptation (i.e., physics-informed domain adaptation, PIDA) by constraining the network to learn the modal information of the structure, which helps alleviate the need for extensive training data and enhances damage detection performance. PIDA provides a novel and better solution for structural damage detection.

DISCRETE TOPOLOGY AND SIZING OPTIMIZATION SOLVED WITH HIERARCHICAL-INSPIRED DEEP REINFORCEMENT LEARNING

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ABSTRACT

The discrete optimization of structures considering both discrete elements and discrete design variables can be formulated as a sequential decision process solved using deep reinforcement learning, shown in this work to efficiently provide adept solutions to a variety of problems. Beneficially, by modeling the optimization of discrete structures as a Markov decision process (MDP), the set of all feasible design solutions can be precisely represented and the MDP naturally, but not exclusively, accommodates discrete actions. In the context of discrete structural optimization, the states of the MDP correspond to specific structural designs represented as finite graphs, the actions correspond to specific topological and parametric design grammars which alter and transition the design to a new state and graph configuration, and the rewards are related to the improvement in the altered graph configuration's performance with respect to the design objective as well as the specified constraints. The consideration of both topological and parametric grammars enable the design agent to alter a given structural configuration's element connectivity and assigned element parameters, respectively. However, in considering topological and parametric actions, both the dimensionality of the state and action space and the diversity of the action types available to the agent in a given state becomes significantly large, making the MDP learning task challenging. This work addresses optimization problems with large and diverse state and action spaces by significantly extending the deep reinforcement learning (DRL) approach implemented in prior work [1]. Specifically, a deep neural network architecture, adapted from hierarchical-inspired deep reinforcement learning (HDRL), is developed to better equip the agent in learning the type of action, including topological or parametric design grammars to apply, reducing the complexity of possible action choices available to the agent in a given state. This MDP-HDRL framework is applied to the discrete optimization of planar trusses considering both discrete elements and multiple discrete cross-sectional areas with the objective of minimizing displacement at a given node for a given external force(s), subject to volume and stability constraints. Through qualitative comparison with other considered alternative methods, the framework is observed to adeptly learn policies that synthesize high performing design solutions with respect to the design problem's specified objective and constraints.

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Advances in regional hazard modeling and risk assessment
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ADVANCING REGIONAL LANDSLIDE RISK ASSESSMENT BASED ON HYBRID DATA-DRIVEN AND PHYSICS-BASED SUSCEPTIBILITY MAPPING MODEL: A PIXEL-TO-SLOPE TRANSFORMATION

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ABSTRACT

Existing regional landslide risk assessments are mainly based on the pixel unit (also referred to as grid or cell units), which often results in significant disparities in risk levels within the same slope unit. This makes it challenging for engineers to accurately delineate high-risk areas. Addressing this issue, this study makes several contributions: (1) To date, very few studies have attempted to complement the advantages of data-driven and physics-based models for susceptibility mapping. We propose a pixel-based hybrid susceptibility mapping model, integrating infinite slope stability analysis and logistic regression using the optimal explanatory factors (elevation, land-cover type, safety factor). (2) A pixel-to-slope transformation method is introduced. Slope units are extracted through hydrological analysis, and the mean and maximum values of pixel susceptibility within each slope unit are calculated and analyzed. These two statistical parameters are then used to characterize the susceptibility of the slope units. The differences in susceptibility mapping results when using the mean value versus the maximum value for the transformation are compared. (3) A loss in accuracy occurs after transformation. To address this issue, a calibration method based on the standard deviation of susceptibility is proposed. It is recommended to conduct field verification when the standard deviation within a slope unit exceeds a certain threshold. The threshold depends on the available human and material resources in the specific area. (4) Population vulnerability and economic vulnerability are quantitatively analyzed, and a comprehensive vulnerability assessment matrix is proposed. A risk assessment matrix based on susceptibility and vulnerability is then constructed. Typical landslide-prone regions in the Three Gorges Reservoir, China, are used as the study area. The results show that the pixel-to-slope transformation of susceptibility mapping results significantly enhances their practicality in engineering applications, though some loss in accuracy occurs during the transformation. This accuracy loss can be effectively mitigated through the proposed calibration method. As the area covered by field verification increases, the area under the curve (AUC) value gradually improves. For example, by setting a threshold for the standard deviation of susceptibility at 0.3, conducting field verification across approximately 11.96% of the total area of Wushan County could increase the AUC value from 0.779 to 0.878. This study provides an easy-to-implement and effective method for regional landslide risk assessment.

Mechanics and modeling of pavement structures and materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DEVELOPMENT OF PLASTICITY-BASED FATIGUE MODEL IN ASPHALT BINDER

Haifang Wen[1]

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ABSTRACT

Fatigue is one of major distresses in flexible pavement. Asphalt binder is the essential constituent in an asphalt mixture. Numerous studies have strived to develop models to predict fatigue behavior of asphalt binder, such as dissipated energy and viscoelastoplastic continuum damage model. However, improvement is still needed to develop robust fatigue model. This study aimed to develop the plasticity-based fatigue model for asphalt binder. This approach integrates creep tests with cyclic tests by regulating the load ratio (R), enabling precise control over the oscillation amplitude (A) and steady shear stress (S) of the applied load. Eyring's activated flow theory and the Sigmoidal model are utilized to characterize the plastic flow behaviors of asphalt within the examined temperatures and stress range. An effective fatigue prediction model is proposed to estimate asphalt materials' cycles to failure. The research findings demonstrate that Eyring's activated flow theory properly elucidates the intricate plastic flow kinetics observed in asphalt creep tests. The model developed in this study provides reasonable predictions that align with the cycles/time to failure measured in tests under various loading paths (R=0.1, 0.3 ,0.5, 0.7, 1) and temperatures.

EXTRAPOLATING WIND-INDUCED PRESSURES ON ROOF SOFFITS OF LOW-RISE BUILDINGS USING FEW-SHOT LEARNING

Yanmo Weng[1] and Stephanie Paal[1]*

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ABSTRACT

Current wind standards assume identical external wind pressure coefficients on roof soffits and adjacent wall surfaces. However, recent experiments suggest that this correlation significantly decreases with an increase in overhang width. This research introduces a few-shot learning model addressing the need for a machine learning approach that can more accurately and efficiently obtain the wind pressure coefficients on roof soffits when the overhang width is large (i.e., larger than 2 ft). A few-shot learning model is proposed to extrapolate the wind-induced pressures on roof soffits for low-rise buildings based on the wind tunnel dataset investigating three large overhang widths (2.4, 4.8, and 7.2 inches in 1:10 scale models) conducted at the Wall of Wind (WOW) Experimental Facility. Prior knowledge relating to zonal information and wind directions shown in the standard of minimum design loads and associated criteria for buildings and other structures (ASCE 7) is incorporated into the model. The proposed few-shot learning model was trained on scale model buildings with overhang widths of 2.4 and 4.8 inches and tested on a 7.2-inch overhang width case. A special set, named the ‘shot set’, is used in the proposed algorithm which only contains 5% of the 7.2-inch overhang width data samples, and the remaining 95% forms the testing set. The proposed meta-learning algorithm is trained on the training set to obtain good initial model parameters. With only a few gradient descent updates based on the data from the small ‘shot set’, the trained model can achieve good prediction performance for the test set data. When predicting the minimum wind pressure coefficient for both the southside and eastside soffit surfaces, low mean-squared errors (0.135 for the Southside and 0.152 for the Eastside) and high coefficient of determination values (0.783 for the Southside and 0.794 for the Eastside) were observed. This study marks the first application of few-shot learning techniques to extrapolate wind pressures across different roof overhang widths and provide reliable predictions that outperform the weak correlation between the soffit and the adjacent wall surface assumed currently. This model reduces reliance on physical wind tunnel experiments and requires only a low-resolution measurement tap configuration.

Advances in computer vision, deep learning and artificial intelligence for structural health monitoring and inspections

May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ROBUST VISION-BASED SUB-PIXEL LEVEL DISPLACEMENT MEASUREMENT USING A COARSE-TO-FINE STRATEGY

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ABSTRACT

Structural displacement has been a crucial proxy for the performance and health of a wide variety of civil infrastructure. Traditional displacement measurement approaches are costly, labor-intensive, and are primarily restricted to a few discrete points. Over the last decade, computer vision-based measurement approaches have been proposed to overcome these limitations, achieving non-contact and dense displacement measurement. In particular, phase-based optical flow (PBOF) has the capability of providing accurate and robust drift-free structural motion. However, conventional PBOF is restricted to estimation of small displacements. Herein, a coarse-to-fine strategy is proposed to extend the PBOF method to large-scale displacement measurement. First, the video is pre-processed to remove possible lens distortion, image noise and to select the target for measurement. Subsequently, the pixel location of the target in the current video frame is determined using weighted normalized cross-correlation matching (WNCC); reduction of the computation burden of this step is also considered. Finally, the displacement correction term is computed using the proposed improved PBOF algorithm, which is invariant to uniform illumination changes and can avoid potential phase wrapping issue. The refined displacement with sub-pixel level accuracy is obtained by combining the coarse displacement with the correction term. The efficacy of the proposed approach was validated with a base-excited 3-story building model in the laboratory. The results demonstrated that the proposed method achieves drift-free large displacement measurement with high efficiency, accuracy, and robustness.

Innovations and advances in passive, active, and semi-active structural control
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

INVESTIGATION OF A VARIABLE LEAD ROTATIONAL INERTIA MECHANISM

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[1]*University of Tennessee*

ABSTRACT

The increasing interest in nonlinear rotational inertia mechanisms (RIMs) stems from their diverse applications in energy storage and vibration control. Unlike a linear RIM, the effective mass produced by a nonlinear RIM can continuously vary during the response of the structure it is attached to. Most of the current research focuses on a specific type of nonlinear RIM that produces variable mass effects via a flywheel with masses incorporated into it that shift position based on the rotational velocity of the flywheel. While other types of nonlinear RIMs may have performance or practicality benefits, research into alternative forms of nonlinear RIMs is rare. This study addresses this gap by investigating the dynamic behavior and vibration control of a variable lead RIM. This RIM utilizes a ball screw mechanism to convert translational motion into the rotational motion of a flywheel, but the lead changes along the length of the shaft of the ball screw. The result of this configuration is that the effective mass provided by the device is a function of the relative displacement between the device's attachment points. The mechanism and dynamic model of the variable lead RIM is presented. A physical realization of a variable lead RIM attached to a single-degree-of-freedom mass-spring-damper system using a variable lead ball screw was produced as a part of this study. The natural frequency and response measures were evaluated from experimentally produced frequency response functions. The results of this study highlight the ability of variable lead RIM to shift the natural frequencies of the structure it is attached to and reduce the response of a system subjected to external excitation. The results of this work will encourage the further study of these innovative devices.

Advances and applications of elasticity within applied mechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

INELASTIC PROCESSES IN MATERIAL EVOLUTION WITH APPLICATION TO FRONTAL POLYMERIZATION

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ABSTRACT

We present a new thermodynamically consistent model for material evolution with application in frontal polymerization. The material evolution is modeled via the dependence of material parameters on an internal variable that represent the degree of cure. The model is motivated by experimental studies that characterize the evolution of material properties where the material is assumed to be elastic with continuously evolving material parameters. When evolving material parameters for materials that stiffen with time are employed in standard constitutive equations, it not only leads to violation of the second law of thermodynamics, but also result in non-physical behavior. To satisfy the thermodynamics constraints, an inleastic process that corresponds to the energy consumed in the evolution of the material needs to takes place concurrently. The inelastic process is formulated through multiplicative decomposition of the deformation gradient by introducing an internal variable representing inelastic strain. Finally, the flow rule for the inelastic strain is derived to enforce non-negative entropy production and to eliminate the non-physical behavior in the model.

The flow rule is applied alongside a thermo-chemo-mechanical model for frontal polymerization. The model considers factors, namely, heat generation, heat transfer, and reaction kinetics that incorporates the rate at which the monomers are converted into polymers with associated heat release. The balance of momentum and balance of energy equations are solved using stabilized finite element method that is consistently derived via Variational Multiscale Method (VMS). An algorithm that simulates the path of the printing process is employed in the printing simulation and several interesting test cases are presented.

KIRIGAMI STRAIN-RATE EFFECTS

Christopher Willett[1] and Martin Walker[1]*

[1]University of Surrey

ABSTRACT

Kirigami, an ancient art form originating from the delicate craft of paper cutting, has emerged as an inspiration for modern engineering pursuits. Its principles, transforming 2D sheets into complex 3D structures, have ignited an era of innovation across multidisciplinary domains, encompassing deployable structures, advanced medical devices, and stretchable electronics.

A captivating facet lies in kirigami's potential to craft robust systems engineered to absorb and dissipate energy during highly dynamic events, such as blasts or impacts. When constructed from metallic materials exhibiting elastic-plastic behaviour, kirigami structures present a promising bedrock for pioneering concepts in energy dissipation systems.

Our exploration focuses on deciphering how varying strain rates impact the mechanical behaviour of kirigami structures. Employing reduced-order analytical models alongside finite element analysis, our investigation reveals the evolution in the behaviour of a simple parallel-cut kirigami configuration under increasing strain rates.

This evolution manifests as a shift from uniform to sequential deformation, akin to the behaviour observed in cellular structures under dynamic loads. Our comprehensive study explores the intricate relationship between cut pattern and strain-rate sensitivity, unravelling their influence on critical factors like dissipated energy and transmitted reaction forces. Moreover, we delve into how the cut pattern governs the structure's deformation mode and influences its failure mechanism.

Understanding and managing the wildfire problem
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

RESIDENTIAL EXTERIOR WALL ASSEMBLY – RESPONSE TO EXPOSURE FROM ADJACENT POST-FLASHOVER COMPARTMENT FIRE

Daniel Gorham[1], Joseph Willi[1] and Gavin Horn[1]*

[1]UL Fire Safety Research Institute

ABSTRACT

Fire spread between buildings can overwhelm firefighting resources and can result in catastrophic wildland-urban disasters and conflagration events. When a building or structure ignites and burns it becomes a source of thermal exposure (radiant heat and direct flame contact) to adjacent targets, including neighboring buildings. Exterior walls comprise a large portion of typical residential structure's surface area and interfaces with several other building components (doors, windows, eaves, vents). If the exterior wall ignites fire penetrate through the assembly and/or spread (vertically and/or laterally) to impact other building components and subsequently enter the structure. In this study experiments were conducted to examined three residential exterior wall assemblies installed on a 4.9 m wide by 4.3 m high target façade: T1-11 plywood over oriented strand board (OSB) sheathing; Exterior Insultation and Finish System (EIFS) over exterior gypsum sheathing; and concrete fiberboard over OSB sheathing. The source exposure was a 3.7 m wide by 2.4 m deep by 2.4 m high compartment fire with a 2.4 m wide by 2.4 m high opening that was allowed to flashover. Separation distances between the source compartment and target façade ranged from 1.8 to 4 meters. Temperature and heat flux at the surface of the target façade were measured and response-to-fire of the wall assemblies was evaluated.

Understanding and managing the wildfire problem
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

WINDOW FAILURE DURING EXTERIOR FIRE EXPOSURE

Joseph Willi[1], Daniel Gorham[1] and Gavin Horn[1]*

[1]UL Fire Safety Research Institute

ABSTRACT

Windows can be a vulnerability of structures exposed to exterior fires, like in the case of wildland-urban interface (WUI) fires. Numerous WUI fire case studies have identified the impact of radiative heat transfer to windows on structure loss. When windows fail, they provide a pathway for embers and/or flames to enter the structure and ignite interior contents.

Research conducted by UL's Fire Safety Research Institute has provided additional insight into window failure during fire exposure. Experiments were performed to study the reaction of different types of dual-pane windows when exposed to a post-flashover compartment fire. Double pane window assemblies with both panes plain (annealed) glass, both panes tempered glass, and one pane plain glass, one pane tempered glass were examined.

For each experiment, eight windows were mounted in a target facade placed across from a source compartment with an attached facade to simulate the exposure of a structure fire to a neighboring structure. The fire was ignited in the source compartment. After reaching flashover, the fire continued to vent out the front opening, exposing the target facade to the spill plume generated by the post-flashover fire. The duration of post-flashover exposures ranged from approximately four to ten minutes. Incident heat flux at the target facade and the heat flux transmitted through the window pane assemblies were measured during each experiment.

In general, plain (annealed) glass panes failed notably earlier than tempered glass panes. For windows with one pane plain glass and one pane tempered glass, the orientation of the panes impacted the performance of the window assembly. The average percent heat flux transmitted through the pane assemblies was similar across the different window types. Heat fluxes measured behind window pane assemblies exceeded critical values for autoignition of common household materials, even before any pane failure occurred in many cases.

This presentation will begin with a brief overview of the WUI fire problem and the role of structure-to-structure fire spread during WUI fire events. The impact of windows on fire spread and the extent to which WUI building codes address windows will be highlighted. Then, the experiments conducted for this research will be introduced. Key experimental results and takeaways will be discussed with an emphasis on improving WUI building codes and structure hardening guidance for homeowners in areas prone to WUI fire hazards.

Meshfree, peridynamic, and particle methods: Advancements and applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

AN ASSESSMENT OF THE APPLICABILITY OF MODERN RKPM METHODS TOWARDS A CONCRETE SIMULATION UNDER EXTREME EVENTS

Dominic Wilmes[1], Michael Hillman[1] and Joseph Magallanes[1]*

[1]*Karagozian and Case, Inc.*

ABSTRACT

Due to its widespread usage in a variety of vital structural applications and infrastructure, the safety and performance of concrete under extreme events, such as impact or blast, is essential to understand and be able to calculate predictively. Towards this end, a number of constitutive models have been developed which seek to capture the wide range of behaviors present in concrete such as those related to hardening, softening, rate effects, fracture, etc. However, these material models only comprise a portion a of a given physics-based numerical analysis as they generally represent a discrete material point in a larger numerical framework. As a consequence, capturing large scale discontinuous phenomenology of concrete response such as fracture, fragmentation, scabbing, and spall are often dependent on the numerical framework the material model is embedded in.

In this work, the advantage of utilizing meshfree methods to provide this robust numerical framework for treating concrete under extreme events will be demonstrated using problems which demonstrate a wide range of concrete phenomenology. A series of concrete benchmark problems will be compiled which seek to show several types of phenomenology found within problems involving concrete materials. A modern RKPM [1] numerical code, KC-FEMFRE, will be applied to each of these benchmarks and the results and efficiency from running these benchmarks will be documented compared against previous results taken from open literature, widely-used commercial solid mechanics codes, and experimental results, when applicable. To ensure fair comparison between existing solvers, the K&C Concrete model [2] will be leveraged as a VUMAT in all simulation codes utilized in this study. This will alleviate any differences that might be constitutive model implementation specific and demonstrate applicability of meshfree for this problem domain against comparable options.

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Infrastructure assessment automation with robotics, deep learning and digital twins
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

INVESTIGATING AND COMPARING 3D IMAGING TECHNIQUES FOR INSPECTIONS OF STRUCTURE RETAINING WALLS

Maxwell Wondolowski[1], Alexandra Hain[1], Sarira Motaref[1] and Michael Grilliot[2]*

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ABSTRACT

This presentation will discuss ongoing research into the use of 3D imaging techniques in civil engineering that is seeking to improve the accuracy, completeness, and efficiency of retaining wall inspections. Traditional inspection methods for retaining walls rely on inspectors to make qualitative assessments of the structure that inform a numerical rating system [1]. 3D imaging accurately captures the entire structure, going beyond the qualitative assessments and collection of discrete points that current retaining wall inspections utilize [2]. The presentation will discuss the details and evaluation of different methods including Structure from Motion (SfM), LiDAR, and Structured Light Scanning (SLS) for the retaining wall inspection. The first experiment being discussed pertains to a laboratory study that sought to determine the accuracy of SfM recreations of a retaining wall structure when compared to an SLS baseline. Three different cameras of varying quality were used to create SfM models of the lab trial structure that were then compared to their SLS counterparts. Cameras with high quality images yielded higher accuracies and the ‘banana’ or ‘doming’ effects were identified as an issue for iterations of the study that measured a straight section of wall. This study also examined two different means of comparing 3D models in the context of routine retaining wall inspection. Expanding on the work from this initial study, a second study is being conducted that assesses the accuracy of SfM retaining wall models collected in the field through manual UAV flights. This second study seeks to determine how UAV based SfM can best be implemented when site conditions require manual flight. In the third study, the impact of loss in data quality for UAV based LiDAR scans will be explored and compared to terrestrial LiDAR scans and survey measurements.

This research is being conducted to help refine the application of 3D imaging techniques in the specific application of retaining wall inspections as part of a project for the CTDOT.

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BAYESIAN MODEL UPDATING USING INCOMPLETE EIGEN-INFORMATION AND SPARSE IDENTIFICATION

Hoi-Lam Wong[12] and Sin-Chi Kuok[1]*

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[2]University of Notre Dame

ABSTRACT

In this study, a novel Bayesian model updating approach that incorporates structural properties and features extracted from monitoring data is proposed. Previous studies have highlighted the detrimental impacts of modeling discrepancies on subsequent analyses, such as system identification, structural health monitoring, structural control, etc. [1,2]. Taking this into consideration, the proposed approach aims to infuse the available physical information and measurements for configuring the structural model. The proposed approach consists of two folds. Firstly, incomplete noisy eigenpairs obtained from vibration tests are utilized to determine the optimal solution of the mass and stiffness matrix. Thereafter, sparse identification is implemented to develop the governing equation of the concerned dynamical system. Consequently, the modeling inaccuracy induced in the eigen-information is compensated by the sparse identification while the structured system matrices mitigate the instability of the sparse identification. Moreover, as the benefit of Bayesian inference, the uncertainties of all estimates and the modeling performance can be quantified in terms of probability density functions [3]. It provides useful information to interpret the reliability of the estimation and modeling outcomes. The proposed approach successfully integrates physical information and limited data for optimal structural modeling with quantified uncertainty. To demonstrate the performance of the proposed method, we present an illustrative example of a bridge structure under various modeling conditions.

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4M (modeling of multiphysics-multiscale-multifunctional) engineering materials and structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

PHASE-FIELD MODELING ELECTRO-CHEMO-MECHANICAL COUPLING FOR ADVANCED CIVIL ENGINEERING MATERIALS

Congjie Wei[1]*, In Kyu Jeon*[1]*, Yuxiang Gan*[1]*, Yong-Rak Kim*[1] *and Chenglin Wu**[1]

[1]*Texas A&M University*

ABSTRACT

Civil engineering materials have come a long way to satisfy our growing demands of buildings and infrastructure such as smart (i.e., sensing), resilient (i.e., physical resistance), sustainable and durable (i.e., tunable chemical reactivity and stability), as well as energy storage capable (i.e., heat and electricity). This requires an in-depth understanding of the often-involved electro-chemo-mechanical coupling phenomenon that occurs during the synthesis, process, and forming of these advanced materials for various functions. In this paper, we introduced an energy formulation that combines the electrical, chemical, and mechanical potentials, as well as ionic capacitance potential, to achieve realistic coupling between the electro-chemo-mechanical coupling. The novel phase-field damage functionals will be introduced to show convergence and coupling among multi-physical fields. Specific examples, including a corrosion-cracking and an ionic store-and-release process, are benchmarked in a 1D setting by comparing with semi-analytical solutions with the help of the Laurent series of complex functions. The 2D benchmark cases were also conducted to show the capability and performance of the proposed phase-field modeling framework. In addition, a data-driven reduce-order phase-field modeling approach is also presented with potential phase-switching using a machine-learning-based inversion approach. A case study on the corrosion-cracking problem is demonstrated using the proposed approach.

Resilience of coastal structures, systems, and community subjected to hazards
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ENHANCING THE RESILIENCE OF COASTAL BRIDGES: THE INFLUENCE OF BOX GIRDER GEOMETRY ON WAVE FORCES VIA SPH SIMULATIONS

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ABSTRACT

The potential increase of the intensity and frequency of natural disasters led by climate change indicates higher risks for coastal bridges: they may be lifted off the pier or otherwise fail during hurricane and tsunami strikes because of elevated water and wave forces. This project investigates various geometries of box girder bridges via smoothed particle hydrodynamics (SPH) modeling, evaluating effective geometric forms and vulnerability. Specifically, we investigate the influence of the angle difference between the web and the top flange, as well as the integration of parapets on wave forces, including the maximum uplift force and the maximum horizontal force. Different wave characteristics and bridge elevations are considered. While both hurricane-induced and tsunami-induced waves would cause damage to coastal box girder bridges, we limit the scope to tsunami-induced waves and thus, solitary waves are employed. The numerical scheme is first validated by existing data in literature and then implemented for a parametric study. It is shown that the angle difference between the web and the top flange plays a significant role in the magnitude of the wave forces, especially when the bridges are elevated and tall waves strike. Moreover, the integration of parapets leads to higher risks for coastal bridges. The results provide insights on effective box girder bridge forms for coastal hazard mitigation, facilitating future research on innovative design of coastal bridges.

Towards resilient coastlines: Advancements and new approaches
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

LIFE-CYCLE COST ASSESSMENT FOR PERFORMANCE-BASED WIND DESIGN OF A TALL CONCRETE BUILDING EQUIPPED WITH DAMPING SYSTEMS

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ABSTRACT

The performance-based wind design (PBWD) methodologies attract growing interest in recent years. Industries, in general, welcome this transition since the experience from performance-based earthquake engineering indicates the PBWD may not only improve building response under extreme wind excitations, but also increase structural economy by allowing for nonlinear response in deformation-controlled components. However, the fact that structural wind design is usually controlled by the comfort criteria poses great challenges of taking full advantage of nonlinear behaviors and hence yields low economic benefits. The installation of a damping system shows advantages to improving the structural comfort behavior in an economically efficient way. In this study, a tall concrete building developed under the guidance of PBWD is equipped with two damping systems, namely passive viscous dampers and semi-active controlled magnetorheological (MR) dampers. To evaluate the economic benefits of both damping systems, a comparison study has been made using the life-cycle cost considering the initial design, installation of damping systems, and maintenance under wind hazards.

Advances in computer vision, deep learning and artificial intelligence for structural health monitoring and inspections
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

PHYSICS-INFORMED FAILURE PREDICTION FRAMEWORK USING HYSTERETIC LOOPS OF RC COLUMNS

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[1]National Taiwan University
[2]National Taipei University of Technology
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ABSTRACT

The hysteretic performance of reinforced concrete (RC) columns is of paramount importance in the seismic analysis of bridge systems, as it dictates the overall stability and load-bearing capacity, thereby ensuring resilience against seismic forces and upholding public safety. The cyclic loading test and numerical modeling are frequently employed for constructing the hysteretic behavior and accessing the damage of RC columns observed under cyclic loads. While cyclic loading tests can capture the structural response in experiments, they incur high costs and demand substantial time and labor resources. In contrast, numerical methods offer efficient modeling of complex systems but may introduce deviations from real-world scenarios, compromising the precision of simulation results. In this study, a physics-informed deep generative framework is proposed, which is composed of two components, i.e., hysteresis curves prediction and surface damage generation. A sequence-to-sequence (Seq2Seq) model is developed to bridge the gap between the hysteresis curves, which are simulated from the finite element models and monitored in the experiments, respectively. Additionally, the physical features are extracted to provide comprehensive information for the condition of the generative model, which is developed to forecast the surface damage patterns of the bridge columns. Trained with 5 hysteresis loops and 110 surface damage samples obtained from cyclic loading tests conducted at the National Center for Research on Earthquake Engineering (NCREE) in Taiwan, the proposed framework can reconstruct the 5 hysteresis loops with a mean squared error of 0.0026 KN and generate the surface damage images of Fréchet Inception Distance (FID) 45.99. By incorporating information from the hysteresis loops, the generative model can predict damage patterns throughout the entire cyclic tests, even those not present in the training dataset. Numerous experiments have confirmed that incorporating additional physical information improves the fidelity of synthetic surface damage patterns. The proposed framework allows bridge engineers to assess potential damages and evaluate the hysteretic performance of RC bridge columns during seismic design and retrofit.

Repair and assessment of deteriorating critical infrastructure
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EXPERIMENTAL DESIGN AND DEEP NEURAL NETWORKS FOR PREDICTING THE CONDITIONS OF STRUCTURALLY DEFICIENT BRIDGES

Olivia Smith[1], Weidong Wu[1], Joseph Owino[1], Yu Liang[1], Lan Gao[1] and Dalei Wu[1]*

[1]The University of Tennessee at Chattanooga

ABSTRACT

The structural condition of bridges is influenced by a myriad of factors, including type, materials, loads, and environmental conditions. Identifying the most significant factors among these is crucial for assessing durability and serviceability. Experimental design techniques play a pivotal role in discerning the relative importance of these factors. By employing these techniques, a reduced set of influential factors can be determined and utilized as inputs for deep neural networks.

The reduced model factors are then fed into deep neural networks to train a regression model for predicting the conditions of structurally deficient bridges. Given the vast dataset encompassing over 615,000 bridges nationwide, it is imperative to automatically retrieve relevant data to enhance the efficiency and accuracy of the predictive model.

To achieve this, data mining techniques are employed to identify and extract pertinent information from the extensive National Bridge Inventory (NBI) database. Our research focuses on contributing to the field of data analytics by refining and optimizing the use of the NBI database for predictive modeling in the context of bridge structural conditions. This approach not only enhances the understanding of the factors influencing bridge conditions but also contributes to the broader field of infrastructure management and maintenance.

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PERSONALIZED EMOTION RECOGNITION USING FOOTSTEP-INDUCED FLOOR VIBRATIONS

Yuyan Wu[1], Yiwen Dong[1], Sumer Vaid[1], Gabriella Harari[1] and Hae Young Noh[1]*

[1]Stanford University

ABSTRACT

Emotion recognition, the process of identifying human emotions, enables various applications, including mental health monitoring and emotion-based smart home devices. Previous sensing methods for emotion recognition, such as wearable sensors, cameras, and microphones, are limited by discomfort, visual obstacles, and privacy concerns. To this end, we propose a novel emotion recognition system using footstep-induced floor vibrations which provides a non-intrusive, convenient, and privacy-friendly method for emotion recognition that overcomes the limitations of other methods. The underlying principle of our method is that individuals' emotional states influence their gait patterns, which, in turn, impact the floor vibrations induced by their footsteps. We can infer individuals' emotional states by capturing and analyzing unique gait patterns associated with various emotional states, sensed through footstep-induced floor vibrations. The main research challenge is that this approach performed poorly when encountering individuals who were newly observed without any samples in the training set. The poor performance is mainly due to the differences among individuals’ gait patterns resulting from their diverse walking habits and body configurations.

To address this challenge, we develop a personalized emotion recognition model that recognizes gait differences among people by comparing the similarities between the newly observed person and each person in the training set. Specifically, we first pre-train an emotion recognition model based on the footstep-induced floor vibration data in the training set. Then, we calculate the gait similarity index between the newly observed person and each of the people in the training set based on the learned representations of the footstep-induced floor vibrations obtained from the pre-trained model. Subsequently, we update and adapt the personalized emotion recognition model by assigning higher weights to individuals in the training set who exhibit similar gait patterns to the newly observed person. To evaluate our system, we conducted a real-world walking experiment with 20 participants. Participants assessed their emotions using the Self-Assessment Manikin emotion survey, including rating scales for valence (pleasant vs unpleasant) and arousal (calm vs excited), with scores between 1 and 9. Our method achieves a Mean Absolute Error of 1.54 for valence score estimation and 1.54 for arousal score estimation. This result is comparable to the state-of-the-art gait-based emotion recognition approaches.

A PHYSICS AND DATA CO-DRIVEN SURROGATE MODELING METHOD FOR HIGH-DIMENSIONAL RARE EVENT SIMULATION

Jianhua Xian[1] and Ziqi Wang[1]*

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ABSTRACT

In this talk, I will present a physics and data co-driven surrogate modeling framework for efficient rare event simulation of mechanical and civil systems with high-dimensional input uncertainties. The framework embodies a fusion of interpretable low-fidelity physical models with data-driven error corrections. The overarching hypothesis is that a well-designed simplified physical model can extract salient features of the original high-fidelity model, while machine learning techniques can fill the remaining gaps between the surrogate and original models. The coupled physics-data-driven surrogate model is adaptively trained using active learning, aiming to maximize the correlation between the surrogate and original model responses in the critical parametric region for a rare event. Due to the strong correlation between the well-trained surrogate and original models, an importance sampling step is finally introduced to drive the probability estimations toward the theoretically guaranteed solutions. I will present numerical examples of static and dynamic problems with high-dimensional input uncertainties (up to 1,000 input random variables) to demonstrate the proposed framework.

Computational geomechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

A MPM LAGRANGIAN-EULERIAN HYDROCODE FOR SIMULATING BURIED EXPLOSIONS IN TRANSVERSELY ISOTROPIC GEOMATERIALS

Mian Xiao[1] and Waiching Sun[1]*

[1]Columbia University

ABSTRACT

Shock waves in geological materials are characterized by a sudden release of rapidly expanding gas, liquid, and solid particles. In engineering applications, these shock waves can often be triggered by underground explosions and has a profound effect on post-explosion behavior controlling. In fact, underground explosions have often been used as an engineering solution for large-scale excavation, stimulating oil and gas recovery, creating cavities for underground waste storage, and even extinguishing gas field fires. As such, hydrocodes capable of simulating rapid and significant deformation under extreme conditions can be a valuable tool for ensuring the safety of explosions. The objective of this paper is to propose the use of material point method (MPM) equipped with appropriate equation of state (EOS) models as a hydrocode suitable to simulate underground explosions of transverse isotropic geomaterials. To capture the anisotropic effect of the common layered soil deposits, we introduce an anisotropic version of the Mie-Gruneisen equation of state is coupled with a frictional Drucker-Prager plasticity model to replicate the high-strain-rate constitutive responses of soil. One advantage that MPM has against many other hydrocodes is the convenience for representing geometry, as those hydrocodes formulated in Eulerian grids have difficulty tracking the deformed material configuration without a level set. By leveraging the Lagrangian nature of material points to capture the historical dependence and the Eulerian calculation of internal force, the resultant model is capable of simulating the rapid evolution of geometry of the soil as well as the high-strain-rate soil mechanics of anisotropic materials. Three numerical examples are presented to verify and demonstrate the shock wave propagation and post-explosion behaviors for both isotropic and anisotropic geomaterials.

Computational geomechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

A MPM LAGRANGIAN-EULERIAN HYDROCODE FOR SIMULATING BURIED EXPLOSIONS IN TRANSVERSELY ISOTROPIC GEOMATERIALS

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ABSTRACT

Shock waves in geological materials are characterized by a sudden release of rapidly expanding gas, liquid, and solid particles. In engineering applications, these shock waves can often be triggered by underground explosions and has a profound effect on post-explosion behavior controlling. In fact, underground explosions have often been used as an engineering solution for large-scale excavation, stimulating oil and gas recovery, creating cavities for underground waste storage, and even extinguishing gas field fires. As such, hydrocodes capable of simulating rapid and significant deformation under extreme conditions can be a valuable tool for ensuring the safety of explosions. The objective of this paper is to propose the use of material point method (MPM) equipped with appropriate equation of state (EOS) models as a hydrocode suitable to simulate underground explosions of transverse isotropic geomaterials. To capture the anisotropic effect of the common layered soil deposits, we introduce an anisotropic version of the Mie-Gruneisen equation of state is coupled with a frictional Drucker-Prager plasticity model to replicate the high-strain-rate constitutive responses of soil. One advantage that MPM has against many other hydrocodes is the convenience for representing geometry, as those hydrocodes formulated in Eulerian grids have difficulty tracking the deformed material configuration without a level set. By leveraging the Lagrangian nature of material points to capture the historical dependence and the Eulerian calculation of internal force, the resultant model is capable of simulating the rapid evolution of geometry of the soil as well as the high-strain-rate soil mechanics of anisotropic materials. Three numerical examples are presented to verify and demonstrate the shock wave propagation and post-explosion behaviors for both isotropic and anisotropic geomaterials.

Objective resilience: Harnessing emerging technologies for enhancing infrastructure and community resilience
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

INTELLIGENT AGRICULTURAL MANAGEMENT SUBJECT TO CLIMATE VARIABILITY

Shaoping Xiao[1] and Zhaoan Wang[1]*

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ABSTRACT

According to a 2022 report from the United States Department of Agriculture (USDA), total farm production nearly tripled from 1948 to 2017. However, despite the growth, there remains a global food shortage. On the other hand, agricultural management, with a particular focus on fertilization strategies, holds a central role in shaping crop yield, economic profitability, and environmental sustainability. While conventional guidelines offer valuable insights, their efficacy diminishes when confronted with extreme weather conditions, such as heatwaves and droughts. Given these pressing issues, it becomes imperative to leverage new technologies to boost farm production, and one such solution is Precision Agriculture (PA). Precision agriculture, also known as ``precision farming'' or ``prescription farming,'' utilizes information and technology-based agricultural management systems. These systems enable farmers to tailor their soil and crop management practices precisely to various weather/soil conditions on individual farmlands.

In this study, we introduce an innovative framework that integrates Deep Reinforcement Learning (DRL) with Recurrent Neural Networks (RNNs). Leveraging the Gym-DSSAT simulator, we train an intelligent agent to master optimal nitrogen fertilization management. Through a series of simulation experiments conducted on corn crops in Iowa, we compare Partially Observable Markov Decision Process (POMDP) models [1] with Markov Decision Process (MDP) models [2]. Our research underscores the advantages of utilizing sequential observations in developing more efficient nitrogen input policies. Additionally, we explore the impact of climate variability, particularly during extreme weather events, on agricultural outcomes and management. Our findings demonstrate the adaptability of fertilization policies to varying climate conditions. Notably, a fixed policy exhibits resilience in the face of minor climate fluctuations, leading to commendable corn yields, cost-effectiveness, and environmental conservation. However, our study illuminates the need for agent retraining to acquire new optimal policies under extreme weather events. This research charts a promising course toward adaptable fertilization strategies that can seamlessly align with dynamic climate scenarios, ultimately contributing to the optimization of crop management practices.

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Molecular scale modeling and experimentation
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

POTENTIAL DEVELOPMENT, MOLECULAR DYNAMICS, AND MULTISCALE MODELING OF TIB AND TI/TIB COMPOSITES

Shaoping Xiao[1], Siamak Attarian[2], Akram Ghaffarigharehbagh[1] and Yingbin Chen[1]*

[1]The University of Iowa
[2]University of Wisconsin

ABSTRACT

Boride ceramics, particularly titanium borides (TiB), are favored materials in extreme conditions due to their exceptional hardness and melting points. Titanium/titanium boride (Ti/TiB) composites exhibit promising potential for applications in aerospace, automotive, and biomedical industries. Despite their significance and the considerable effects invested in their fabrication and testing, limited modeling and simulations exist regarding the mechanics of these materials at various length scales, primarily due to the absence of reliable and accurate potential functions for Ti-B systems.

This study addresses the gap by employing diverse numerical methods to investigate the mechanics of TiB and Ti/TiB composites. Initially, density functional theory (DFT) is utilized to develop an interatomic potential for the Ti-B system, employing the second nearest-neighbor modified embedded atom method (2NN-MEAM) formulation. Subsequently, Molecular Dynamics (MD) simulations are conducted using the developed potential to explore the mechanics of TiB at the nanoscale, considering the effects of temperature and defects. Finally, peridynamics is employed to study the mechanical behaviors of Ti/TiB composites, particularly under high-speed impact.

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Modeling of materials with interfaces and scales using physics-based and machine-learning methods
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

LINKING MICRO-MORPHOLOGY AND MACRO-MECHANICS: UNCERTAINTY QUANTIFIED PARAMETRICALLY UPSCALED CONSTITUTIVE MECHANICS MODEL (UQ-PUCDM) FOR COMPOSITES THROUGH PHYSICS-BASED MACHINE LEARNING

Yanrong Xiao[1], Deniz Ozturk[1], Xiaofan Zhang[1] and Somnath Ghosh[1]*

[1]*Johns Hopkins University*

ABSTRACT

This work develops an uncertainty qualified, parametrically upscaled constitutive mechanics model (UQ-PUCDM) for composites using Bayesian inference and machine learning methods. PUCDM, a microstructure-sensitive constitutive model, is thermodynamically consistent for multiscale analysis of unidirectional glass fiber-reinforced composites. This model uses explicit functions with Representative Aggregated Microstructural Parameters (RAMPs) that represent statistical distributions of fibers in the microstructure. With machine learning methods, the function forms of the PUCDM equations are determined to reflect the fundamental deformation characteristics of the aggregated response observed in the microstructural statistically equivalent RVEs' finite element model simulations. The UQ-PUCDM framework is built from computational homogenization of finite element simulations performed on a large set of microstructures and various load paths, followed by Bayesian inference from these results to derive probabilistic microstructure-dependent constitutive laws of the macroscopic material response. The framework derives probabilistic micro-structure dependent constitutive laws addressing multiple sources of uncertainty that accrue at the model development and response prediction stages, viz: (i) model reduction error, (ii) data sparsity, and (iii) microstructural variability of the material. A Taylor expansion-based uncertainty propagation method is developed to propagate uncertainties to the material response variables. Several numerical examples are provided to demonstrate UQ-PUCDM's accuracy. This study provides an insight into the physical constraints of applying the machine learning method to small mechanical data sets.

Advances and applications of elasticity within applied mechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

NANOSCALE CYLINDRICAL DEFECTS IN FLEXOELECTRIC SOLIDS

Jinchen Xie[1] and Christian Linder*[1]

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ABSTRACT

Flexoelectricity, characterized as a size-dependent phenomenon, enables strain gradients to induce electric polarization. This effect becomes notably pronounced near defects within flexoelectric solids, where significant strain gradients are typically observed. A comprehensive understanding of internal defects in flexoelectric devices and their associated multiphysics fields is imperative for elucidating their damage and failure mechanisms. Given the prevalence of circular-shaped cavities and inhomogeneities among various defect typologies, this study delves into an extensive investigation of plane strain problems associated with cylindrical cavities and inhomogeneities in flexoelectric solids [1, 2]. For the first time, we derive full-field analytical solutions for these problems, leveraging the principles of flexoelectricity, which encompasses pure strain gradient elasticity theory. Correspondingly, strain gradient elasticity solutions for plane strain problems involving cylindrical cavities and inhomogeneities are also established, marking a novel contribution to the field. Our findings demonstrate that the stiffness of inhomogeneities, the sizes of cylindrical defects, and the loading ratios in biaxial directions significantly influence the local electromechanical coupling behavior near these inhomogeneities. To compare with our analytical findings, we employ the mixed finite element method to approximate the solutions numerically. The congruence observed between the finite element outcomes and the analytical solutions underscores the reliability and rigor of this investigation. In summary, this research provides crucial insights into the behavior of defects in flexoelectric solids and lays a robust foundation for future studies on more complex defect typologies. It is a significant contribution to understanding flexoelectric materials and their applications in advanced technological domains.

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DENOISING CALIBRATION AND PERFORMANCE EVALUATION OF LOW-FREQUENCY MEMS ACCELEROMETERS BASED ON GENERATIVE ADVERSARIAL NETWORK

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[1]Shenzhen University
[2]University of Notre Dame

ABSTRACT

MEMS (Micro Electro Mechanical System) accelerometer has gained considerable attention in recent years since it can be potentially used for smart sensing with edge computing in various fields. For large civil infrastructure, such as long-span bridges, and super-tall buildings, engineers are more interested in knowing the dynamic performance in a low-frequency range which is related to the comfort level and structural safety. In order to capture their modal characters, good performance of anti-noise sensors in a low-frequency band is required. However, noise interfering can not be eliminated from the MEMS sensors during the measurement. To address this issue, an adaptive denoising method for sensor calibration based on the generative adversarial network is proposed, including (i) signal pre-processing; (ii) data network training; and (iii) performance evaluation. Furthermore, a field measurement of the dynamic response of a long-span bridge is carried out with the comparison to conventional instruments. Results have shown the efficiency of the denoising method for civil applications.

EFFICIENT SAMPLE-BASED SENSITIVITY ANALYSIS FOR HIGH-DIMENSIONAL VARIABLES WITH NORMALIZING FLOWS

Ziluo Xiong[1] and Gaofeng Jia[1]*

[1]Colorado State University

ABSTRACT

Sobol' indices have been widely used in global sensitivity analysis to quantify the influence of the uncertainty of input variables on the variance of the system output. Among various approaches for evaluating Sobol' indices, the recently developed sample-based approach uses only one set of samples from an auxiliary probability density function (PDF) to evaluate the sensitivity to all input variables. However, a key step in the approach is to use kernel density estimation (KDE) to estimate the auxiliary PDF, which suffers from the curse of dimensionality and hinders its use for calculating sensitivity for groups of variables, which is of great interest for complex systems with many variables (or subsystems each represented by a subset or a group of variables). To address this challenge, this study extends the sample-based approach by introducing normalizing flows (NF) for efficient and accurate density estimation in place of KDE. NF are a family of methods for constructing complex distributions by transforming a simple PDF through a series of invertible mappings. It is an emerging generative machine learning model that allows not only efficient simulation of samples from a target PDF but also a direct estimation of the corresponding PDF values. The basic idea of the sample-based approach is to construct a joint auxiliary PDF based on the system performance function and PDFs of all input random variables. The Sobol' indices of any random variables (scalar or vector) can then be calculated based on a marginal distribution (of the joint auxiliary PDF) that is estimated with NF from a single sample set from the joint auxiliary PDF. Also, a novel adaptive stochastic sampling technique is proposed to efficiently obtain samples from the joint auxiliary PDF by training NF with a customized loss function minimizing the discrepancy between the learned PDF and joint auxiliary PDF. As an illustration, the proposed approach is applied to two high-dimensional benchmark problems. The results show that the proposed approach can accurately and efficiently evaluate Sobol' indices for high-dimensional input variables of a complex system.

Objective resilience: Computational advancements for performance-based engineering and resilience assessment of communities
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ENHANCING TRAFFIC RESILIENCE FOR EMERGENCY EVACUATION BY EFFICIENT NETWORK-WIDE SPEED LIMIT OPTIMIZATION UNDER UNCERTAINTY

Ziluo Xiong[1] and Gaofeng Jia[1]*

[1]Colorado State University

ABSTRACT

Pressing threats from natural hazards (e.g., hurricanes and floods) have made efficient traffic evacuation critical to ensuring the resilience of vulnerable communities. During emergency evacuation, traffic management policies are often made to enhance the performance of transportation networks. Among the different policies, developing appropriate network-wide speed limits has been recognized as a promising one. To accurately assess the network performance, various uncertainties need to be considered, making the speed limit design computationally challenging because it corresponds to a high-dimensional optimization problem under uncertainty. In this regard, this study develops a new method to reliably and efficiently improve traffic resilience for emergency evacuation. Specifically, a transportation network performance modeling framework is first proposed to incorporate traffic efficiency and traffic safety concerns that are seldomly addressed simultaneously yet necessary in evacuation planning. Moreover, a novel optimization strategy is developed by artificially treating the network-wide speed limits as a high-dimensional random variable and formulating an augmented reliability problem to efficiently explore the uncertain network performance over the entire design space of speed limits. As a key step in the proposed approach, random samples need to be generated from a failure distribution. By leveraging an emerging generative machine learning model (i.e., normalizing flows), an adaptive stochastic sampling technique is designed to efficiently obtain a sufficient number of samples at low cost. Finally, an evolutionary algorithm is applied to derive an optimal speed limit design based on a surrogate of the network performance that is built upon the obtained samples from normalizing flows. The proposed method is applied to a real-world transportation network for demonstration. The results show that the proposed method can effectively resolve the network-wide speed limit design problem, facilitating prompt traffic resilience enhancement during emergency evacuation.

DATA-DRIVEN MODELING OF STOCHASTIC DIFFERENTIAL EQUATIONS

Yuan Chen[1] *and Dongbin Xiu**[1]

[1]*The Ohio State University*

ABSTRACT

We present a numerical framework for learning unknown stochastic dynamical systems using measurement data. Termed stochastic flow map learning (sFML), the new framework is an extension of flow map learning (FML) that was developed for learning deterministic dynamical systems. For learning stochastic systems, we define a stochastic flow map that is a superposition of two sub-flow maps: a deterministic sub-map and a stochastic sub-map. The stochastic training data are used to construct the deterministic sub-map first, followed by the stochastic sub-map. The deterministic sub-map takes the form of residual network (ResNet), similar to the work of FML for deterministic systems. For the stochastic sub-map, we employ a generative model, particularly generative adversarial networks (GANs) in this paper. The final constructed stochastic flow map then defines a stochastic evolution model that is a weak approximation, in term of distribution, of the unknown stochastic system. A comprehensive set of numerical examples are presented to demonstrate the flexibility and effectiveness of the proposed sFML method for various types of stochastic systems.

Molecular scale modeling and experimentation
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

VIRTUAL FORCE FIELD AND COARSE-GRAINED MODELING FOR FAST SIMULATIONS ON CRUMPLING AND ASSEMBLING OF MASSIVE 2D MATERIALS BY DROPLET DRYING

Ziyu Chen[1] *and Baoxing Xu**[1]

[1]*University of Virginia*

ABSTRACT

Two-dimensional (2D) materials, such as graphene, boron nitride and molybdenum disulfide, have attracted tremendous attention over the past few years for their exceptional electronic, mechanical and thermal properties underpinned by their extremely large specific surface area, often demonstrated at the single layer level. However, a bulk form of these 2D materials, either as powders or a monolith is necessary for most applications such as high-performance electrodes in energy storage, filters for waste water/gas treatments in environmental systems, and lightweight structures. Crumping of 2D materials by droplet evaporation creates a new form of aggregation-resistant ultrafine particles with more scalable properties such as high specific surface areas. Here, we will present a computational molecular framework to simulate the simultaneous process of crumpling and self-assembly of massive 2D graphene sheets and their competition by droplet drying. In the framework, a coarse-grained molecular dynamics model will be proposed to model graphene sheets and well calibrated by comparing with the full-scale atomistic model including stretching, bending and adhesive deformation. A virtual force field that exerts on the coarse-grained model of graphene through the well-defined decreasing rate of spherical radius will be developed to mimic the liquid evaporation-induced pressure and is confirmed with good agreement with full-scale simulation on solid-liquid interactions. Comprehensive simulations on graphene sheets in both fully suspended droplet and sessile droplet on a solid substrate will be performed to reveal the evolution of energy and morphology during crumpling and assembling, and the simulation results show remarkable agreement with theoretical predictions. More importantly, good agreement between simulations and theoretical predictions on both overall size and accessible area of assembled stable particle after complete evaporation of liquid will be obtained and compared with experiments. The proposed fast simulation modeling and approach could be extended to study a broad scope of other low-dimensional nanomaterials such as nanowires, nanotubes, nanofibers and nanoparticles, and will provide quantitative guidance for the low-cost manufacturing of their bulk quantities through aerosol-like, or printing process in which fundamental mechanism of large deformation, instability, and self-assembly by solution evaporation are expected.

Recent advances in sensing, SHM, and automated inspections for infrastructure condition assessment: Toward actionable solutions
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ACTIVE AND PASSIVE FUNCTIONALITY OF PIEZOELECTRIC SENSORS FOR MONITORING HIGH-TEMPERATURE PIPING SYSTEMS IN LIQUID METAL REACTORS

Chenxi Xu[1], Talha Khan[1], Muhammad Khan[1], Matthew Daly[1], Alexander Heifetz[2], Derek Kultgen[2], Miguel A. Gonzalez Nunez[3], Ed Lowenhar[3] and Didem Ozevin[1]*

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[2]Argonne National Laboratory
[3]MISTRAS Group Inc

ABSTRACT

Piezoelectric sensors can function as transmitters and receivers, making them suitable for passive and active structural health monitoring (SHM) methods. This study combines guided wave ultrasonics (GWU) and acoustic emission (AE) methods to monitor piping systems in advanced nuclear reactors. The AE method can pinpoint the location of defects in pipes in real time by using a linear array of sensors. GWU can classify the defect type and severity once its location is identified using the AE method. The liquid sodium piping network at the Mechanisms Engineering Test Loop (METL) facility at Argonne National Laboratory was instrumented with thirteen piezoelectric sensors strategically placed using waveguides to accommodate the high operational temperature. The sensitivity of the acoustic emission mode was demonstrated through pencil lead break simulations, which showed that the piping system operates as an excellent waveguide. In the guided wave mode, pulse signals were transmitted through each sensor. The experimental results were compared with numerical simulations. Furthermore, the numerical simulations were extended to study damage modes, such as creep and fatigue cracks near welds. Creep damage and fatigue crack were introduced as coalescence of pores and line crack near welds, respectively. The integration of guided wave ultrasonics and acoustic emission methods, coupled with the application of the same sensor network, proves to be a promising approach for SHM of piping systems in advanced nuclear reactors.

A NOVEL SUBMERGED BREAKWATER FOR PROTECTING COASTAL BRIDGES FROM EXTREME WAVES

Guoji Xu[1], Shihao Xue[1], Zexing Jiang[1] and Jiaguo Zhou[1]*

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ABSTRACT

Extreme waves generated by hurricanes, together with storm surges, have led to severe damage and even failures in numerous offshore structures. In this study, an innovative submerged breakwater design, specifically engineered to bolster coastal infrastructure resilience against the devastating effects of extreme waves and storm surges, is presented. This new design, featuring three semicircular shells and a rectangular base, enables modular construction and rapid deployment, providing an alternative in coastal structures protection strategies. Utilizing a sophisticated high-fidelity numerical wave tank, the breakwater's efficacy is scrupulously assessed under an array of stringent conditions, encompassing variations in wave height, water depth, bridge submersion depth, and proximal spacing to the bridge.A second-order solitary wave model is utilized to simulate extreme wave conditions, providing a robust test of the breakwater's capabilities. The results demonstrate a considerable reduction in both horizontal and vertical wave forces on T-girder bridge decks when compared to traditional breakwaters made from the same materials, thus confirming the new design's superior efficacy.

Further examination focuses on three critical aspects of the breakwater's development. Detailed wavelet analysis sheds light on the significance of wave energy redistribution in the time-frequency domain in reducing transient impacting forces. Additionally, a validated ANSYS finite element model is utilized to investigate the dynamic responses of the breakwater under various wave conditions, highlighting the need for attention to tensile stress, particularly at the arch foot region. Nevertheless, the observed maximum tensile stress remains within the safety parameters for widely used construction materials such as C40 concrete, ensuring the design's practicality and safety. A predictive adaptive Kriging-based surrogate model, developed using advanced machine learning techniques, provides further insights into the optimal deployment of the breakwater. According to the model, positioning the breakwater in water depths less than 1.25 times its height can lead to a reduction in wave loads by more than 20%, offering a strategic advantage in coastal defense planning.

In conclusion, this study contributes a meticulously developed breakwater design to coastal infrastructure protection, combining extensive numerical analysis with pragmatic engineering considerations. The findings confirm the design's capacity to reduce the impact of extreme waves on coastal structures, thus offering a substantiated, effective solution to the challenges of coastal engineering.

Modeling and characterization of brittle and quasibrittle fracture
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ASYMPTOTICALLY MATCHED EXTRAPOLATION OF FISHNET FAILURE PROBABILITY TO CONTINUUM SCALE

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ABSTRACT

Motivated by the extraordinary strength of nacre, which exceeds the strength of its fragile constituents by an order of magnitude, the fishnet statistics became in 2017 the only analytically solvable probabilistic model of structural strength other than the weakest-link and fiber-bundle models. These two models lead, respectively, to the Weibull and Gaussian (or normal) distributions at the large-size limit, which are hardly distinguishable in the central range of failure probability. But they differ enormously at the failure probability level of 10^(-6), considered as the maximum tolerable for engineering structures. Under the assumption that no more than three fishnet links fail prior to the peak load, the preceding studies led to exact solutions intermediate between Weibull and Gaussian distributions. Here massive Monte Carlo simulations are used to show that these exact solutions do not apply for fishnets with more than about 500 links.

The simulations show that, as the number of links becomes larger, the likelihood of having more than three failed links up to the peak load is no longer negligible and becomes large for fishnets with thousands of links. A differential equation is derived for the probability distribution of not-too-large fishnets, characterized by the size effect, the mean and the coefficient of variation.

Although the large-size asymptotic distribution is beyond the reach of the Monte Carlo simulations, it can be illuminated by approximating the large-scale fishnet as a continuum with a crack or a circular hole. For the former, instability is proven via complex variables, and for the latter via a known elasticity solution for a hole in a continuum under shear. The fact that rows or enclaves of link failures acting as cracks or holes can form in the large-scale continuum at many random locations necessarily leads to the Weibull distribution of the large fishnet, given that these cracks or holes become unstable as soon they reach a certain critical size. The Weibull modulus of this continuum is estimated to be about triple that of the central range of small fishnets. The new model is expected to allow spin-offs for printed materials with octet architecture maximizing the strength-weight ratio.

Advances in modeling of material damage and fracture
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

UPGRADE OF FRACTURE MECHANICS BY SPRESS-SPRAIN RELATIONS: LIMITING DAMAGE FIELD CURVATURE

Houlin Xu[1], Anh Nguyen[1], A. Abdullah Donmez[1] and Zdenek Bazant[1]*

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ABSTRACT

Realistic simulation of fracture propagation and, especially, fracture branching, is essential for meaningful assessment and prediction of the continued growth of hydraulic crack system in rock. It is expected that lateral branching of the hydraulic cracks may be stimulated by variation of salinity of injected water and its changes. To capture the lateral branching one must consider that the crack is actually a damage band with a front of finite width, governed by a triaxial tensorial damage law. This is evidenced by the recent discovery of the so-called gap test at Northwestern University. To simulate such fracture numerically, the classical crack band model must be adopted. A fresh improvement, called the smooth Lagrangian crack band model (slCBM), which uses the new concept of localization limiter based on displacement curvature limitation and the so-called "spress-sprain" relations, will be used. This improvement is able to resolve the damage variation across the crack band and the variation of crack band width capturing the dependence of fracture energy on the crack-parallel tectonic stresses. All this will be done in the context of inelastic poromechanics.

INSIGHTS INTO THERMOMECHANICAL PROPERTIES OF CROSSLINKED POLYMER NETWORK ASSISTED BY MACHINE LEARNING

Lan Xu[1], Sara Tolba[2] and Wenjie Xia[1]*

[1]Iowa State University
[2]North Dakota State University

ABSTRACT

Crosslinked polymer network materials are distinguished by their complex mechanical and glass-forming properties, a result of their unique molecular characteristics. In this study, we delve into the intricacies of their structure-property relationship using machine learning (ML) techniques. Employing a dataset derived from coarse-grained modeling, we explored a range of sophisticated ML models, including Random Forest, Support Vector Regression (SVR), and Artificial Neural Networks (ANNs). The Random Forest model emerged as the standout performer, distinguished by its minimal Root Mean Square Error (RMSE). To further refine our approach, we implemented ensemble methods and advanced hyperparameter optimization techniques, such as grid search and Bayesian optimization. Our investigations revealed the profound impact of molecular factors, particularly cohesive energy and chain stiffness, on the mechanical attributes of these materials. We ensured the credibility of our ML models through stringent cross-validation and strategies to mitigate overfitting. The insights gained from this study highlight the transformative potential of ML in deciphering and influencing the complex behaviors of polymer networks, heralding a new era of customized material design.

Surrogate modeling for uncertainty quantification, optimization, and statistical inference in engineering applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

AN ADAPTIVE SURROGATE-BASED MULTI-FIDELITY MONTE CARLO SCHEME FOR PROBABILISTIC ANALYSIS OF NONLINEAR SYSTEMS SUBJECT TO STOCHASTIC EXCITATION

Liuyun Xu[1] and Seymour Spence[1]*

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ABSTRACT

To investigate the performance of engineered systems under general stochastic excitation in the context of uncertainty propagation, a considerable number of high-fidelity nonlinear analyses are generally required when implementing many state-of-the-art probabilistic frameworks, which can become computationally infeasible for complex systems. To minimize the computational cost while preserving accuracy, an adaptive surrogate-based multi-fidelity Monte Carlo (MFMC) scheme is presented for efficiently propagating uncertainties and predicting inelastic responses, and therefore, estimating probabilities of failure. In this approach, all available high-fidelity numerical simulations are concurrently employed as the training data for a surrogate model, based on a Gated Recurrent Unit (GRU) deep learning network, for predicting nonlinear dynamic responses which then serves, within the MFMC scheme, as a cost-effective low-fidelity model that correlates well with the high-fidelity model. To derive the quasi-optimal trade-off between the approximation quality of the low-fidelity model and the computational demand for training, an adaptive sampling scheme is introduced. This scheme seeks the minimum training data that ensures an adequate correlation between the high- and low-fidelity models with minimal variance, as determined through K-fold cross-validation. The proposed scheme is demonstrated to be capable of estimating failure probabilities for various limit states of interest through its application to a full-scale high-rise steel building under stochastic wind excitation. In addition to being significantly faster than state-of-the-art high-fidelity probabilistic frameworks, the scheme is remarkably accurate in reproducing the inelastic responses of structural models characterized by complex material behaviors, such as steel fatigue and initial imperfections.

Towards resilient communities: Improvements in natural hazard risk assessment using data-driven methods
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MECHANICAL ANALYSIS OF SEGMENTED TUNNEL STRUCTURES UNDER ACTIVE FAULT ACTIONS

Longjun Xu[1], Heng Zhang[2] and Lili Xie[1]*

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ABSTRACT

To enhance the seismic resilience of transportation infrastructure systems, the idea of a segmented tunnel structure system has been proposed when tunnel engineering passes through active faults. It is believed that segmented tunnels have a better ability to adapt to seismic fault deformations, thereby reducing damage caused by faults and making it easier to restore traffic functions. However, the mechanical properties, failure principles, and applicable conditions of the disconnected segmental tunnel lining still need further study. This work takes a mountain tunnel project as an example, using finite element calculation methods to explore the mechanical properties of fully disconnected tunnel lining under fault action. The orthogonal experimental method was used to analyze the effects of factors such as the length of the lining segment, the width of the fault fracture zone, and the dip angle of the fault on the damage status of the lining at different levels of fault action. Results show that the use of segmented design is an effective measure to adapt to the action of faults. By utilizing the rigid motion between segments, the concentrated displacement of faults can be dispersed, reducing the forced displacement level acting on segmented tunnels and significantly reducing the degree of damage. The factors that affect the range of tunnel damage are found to be: fracture width, lining segment length, and fault dip angle. However, there are significant differences in the performance of tunnel segment lining under different fault action conditions, which have not been mentioned in previous studies. Therefore, a reasonable segment plan should be selected based on the type of active fault. In addition, the ability of segmented tunnels to adapt to fault activity is closely related to the performance of the selected materials. This study further compared and analyzed the stress performance of high-strength concrete and ultra-high strength concrete lining segments under the same fault action conditions. It is believed that materials with higher strength and yield point should be selected as lining materials for segment design.

Topology optimization: From algorithmic developments to applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

TOPOLOGY OPTIMIZATION OF LIQUID CRYSTAL ELASTOMER MATERIALS WITH A NONUNIFORM DIRECTOR FIELD

Tingting Xu[1], Thao (Vicky) Nguyen[1] and James Guest[1]*

[1]Johns Hopkins University

ABSTRACT

Nematic Liquid Crystal Elastomers (LCEs), containing rod-shaped mesogen moieties, are gaining significant attention for their ability to create multi-stimuli responsive actuators, morphing structures, and color-changing materials. The reorientation of these mesogens in response to external stimuli, coupled with network deformation, engenders unique viscoelastic behaviors and enhanced energy dissipation capacity. In this study, we introduce a robust topology optimization framework designed to facilitate the fabrication of monodomain LCE structures with an initially nonuniform director field. By leveraging this framework, it becomes possible to tailor the mechanical and optical properties of the LCEs to specific application needs. In this research, we design our method to simultaneously optimize both structural topology and director patterns in LCE structures. To achieve this, we integrate our algorithm as a User-defined element within the ABAQUS finite element suite to accelerate the processing speed of nonlinear finite element simulations. Furthermore, this study utilizes a time-dependent adjoint method, ensuring numerically precise and efficient design sensitivity analysis. Several numerical examples, focusing on compliance minimization and energy dissipation maximization, are presented to demonstrate the advantages of optimizing both the topology and the initial director field in our designs. These examples underline the effectiveness of topology optimization in fully exploiting the capabilities of initial director patterns. We anticipate that this topology optimization framework will be instrumental in advancing design processes in a broad array of applications, ranging from soft robotics and programmable metamaterials to sophisticated energy absorption systems.

Data-driven approaches to engineering mechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

A NEURAL OPERATOR LEARNING APPROACH TO MODEL POROELASTODYNAMICS OF ROCKS

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ABSTRACT

Coupled physics processes involving fluid flow in porous media play a key role in various engineering and geophysical applications such as CO2 sequestration and energy mining from unconventional reservoirs. This work takes advantage of deep learning to capture the poroelastodynamics of rocks using elastic waveform and acoustic pore pressure measurements. The main challenges in this vein are three-fold, namely: (i) multi-physics nature of data, (ii) multi-scale poroelastic properties such as the Lame constants, permeability coefficient, Biot modulus and effective stress coefficient, and (iii) asymmetric datasets where the measurements are dense in terms of elastic displacement but sparse when it comes to pore pressure. To help address these issues, kernel learning by way of the Fourier neural operators (FNO) [1,2] is employed to model the dynamical behavior of rocks in the frequency domain from partial and/or full waveform data in terms of elastic displacement and pore pressure. To this end, the rock is modeled as a poroelastodynamic operator that maps any external excitation to its associated displacement and pore pressure response such that the rock's constitutive behavior is naturally embedded as network parameters and learned from the data. Compared to classical architectures (defined by maps between finite-dimensional Euclidean spaces), the most notable advantages of FNOs are their resolution independence (thanks to mapping between infinite dimensional spaces) and their extrapolation capability to unseen scenarios (through parametrizing physical operators instead of solution instances). As a result, once the FNO is trained, solving for a new input only requires a forward pass of the network which integrates constitutive modeling, identification of poroelastic properties, and response prediction. By utilizing multi-frequency data as well as proper data and loss function scaling, we demonstrate that a robust and stable operator learning from poroelastic waveforms is achievable.

References:
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Physics informed machine learning (PIML) for mechanics of porous media
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EFFICIENT DNN MODELING OF UNKNOWN PDE SYSTEMS

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ABSTRACT

We will introduce a new framework called Flow Map Learning (FML), designed for the approximation and recovery of unknown time-dependent partial differential equations (PDEs) using solution data. This approach is different from traditional methods, which typically concentrate on identifying individual terms within PDEs. Instead, our focus is on numerically approximating the flow map: the mapping between the solutions at two different time instances, of these PDEs. We present a deep neural network (DNN) structure that closely matches the actual flow map of the PDE, which improves the accuracy of our model's estimates. This DNN-based FML extends to various scenarios, including linear and nonlinear scalar PDEs, systems of PDEs, and differential-integral equations, demonstrating versatility in both one and two dimensions.

Advances in geomechanics and geophysics for modern sub-surface technology and natural hazard
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

SCALING EFFECTS IN REDUCED PHYSICAL TESTS: INSIGHTS FROM A GRADIENT-TYPE NONLOCAL PLASTICITY MODEL

Dawei Xue[1] and Giuseppe Buscarnera[1]*

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ABSTRACT

Mapping the measured performance of small-scale physical models to prototype scale involves grappling with scaling effects stemming from the interaction between the tested system and finite-dimensional plastic deformation zones. Although higher-order continuum models provide opportunities to quantify these effects, no study has assessed the influence of shear deformation zones on the performance of reduced-scale models. This study addresses this gap through gradient-type nonlocal plasticity. Specifically, a hardening-softening non-associative Mohr-Coulomb constitutive model is introduced and augmented with an over-nonlocal formulation. Within this framework, a closed-form expression for shear band thickness in full-field problems is derived. Analyses of Scaling effects are conducted in various systems, encompassing soil specimens under plane strain compression, reduced-scale shallow foundations, and pullout plate anchors. The simulations, in alignment with experimental data, reveal that as the size of the geo-system decreases, the load-displacement responses display heightened load-bearing capacity and more pronounced strength loss with further deformation. Furthermore, it is observed that the spatial extent of the plastic zone is contingent upon the size of the system relative to the intrinsic material length scale. The analyses also indicate that the mode of deformation undergoes a transition from strain localization to a diffuse plastic zone with a reduction in model size. These simulations not only offer valuable insights into the behavior of scaled geo-systems but also inspire the formulation of novel scale correction coefficients. This enhancement of model-to-prototype rescaling procedures, contingent on shear band thickness and system size, has the potential to improve the accuracy with which centrifuge test measurements can be used for engineering design.

Engineering Mechanics Institute Conference and Probabilistic Mechanics & Reliability Conference (EMI/PMC 2024)

Computational methods for stochastic engineering dynamics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

STOCHASTIC SUBSPACE VIA PROBABILISTIC PRINCIPAL COMPONENT ANALYSIS FOR MODEL-FORM UNCERTAINTY

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ABSTRACT

This paper proposes a probabilistic model of orthonormal matrices based on the probabilistic principal component analysis (PCA). Given a sample of vectors in the embedding space, commonly known as a snapshot matrix, this method uses quantities derived from the PCA to construct distributions of the sample matrix as well as orthonormal matrices of all ranks. It is applicable to projection-based reduced-order modeling methods, such as proper orthogonal decomposition and related model reduction methods. Whereas existing methods use the tangent space of a matrix manifold to carry out probabilistic modeling of reduced-order basis, the proposed method carries out the probabilistic modeling of the subspace itself. This approach helps us find the probability distribution's analytical form in certain cases. The stochastic reduced order basis (SROB) thus constructed can be used, for example, to characterize model-form uncertainty in computational mechanics. The proposed method has multiple desirable properties: (1) it is naturally justified by a probabilistic interpretation of PCA and has analytic forms for the induced probabilistic models on related matrix manifolds; (2) it satisfies linear constraints, such as boundary conditions of all kinds, by default; (3) it has only one hyper-parameter, which greatly simplifies hyper-parameter training; (4) its algorithm is very easy to implement. We compare the proposed method with existing approaches visually in a low-dimensional example and demonstrate its performance in characterizing the uncertainty in a dynamics model of a space structure.

PROJECTION OF TROPICAL CYCLONE ACTIVITIES UNDER FUTURE CLIMATE

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ABSTRACT

To investigate the TC genesis under future climate, future TC events will be produced by using the global climate modeling (GCM) data. Eight global climate models of CMIP6, including GFDL (Geophysical Fluid Dynamics Laboratory Climate Model) climate models (e.g., CM4 and SPEAR), will be used. The following two combined climate change scenarios will be considered in this project, which are SSP5-8.5 and SSP3-6. First, the annual occurrence number will be generated based on the Genesis Index (GI) (Tippett et al., 2011; Scamargo et al., 2014). This index is based on the Poisson Regression of historical TC occurrence number and large-scale environment factors obtained from the GCM data. Second, the probability function of TC genesis location/time for future climate will be obtained by modifying the function under the current climate. To represent the future TC climatology, 10,000 simulation years of TC events will be produced using Monte Carlo Simulations by following the probability density distribution under future climate. Then, statistical analysis will be conducted to characterize the TC climatology under the given global climate, in terms of the spatial and temporal (seasonal and interannual) variability of the “observed” TCs under future climate.

Design and additive manufacturing of engineering structures and materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MULTI-PHYSICS MODELING FOR METAL ADDITIVE MANUFACTURING: MELT POOL DYNAMICS, DEFECTS, AND POWDER SPATTERS

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ABSTRACT

Existing metal additive manufacturing (AM) models have difficulty handling the laser-metal interaction and associated boundary conditions (BCs) that significantly influence part quality metrics, such as defect and surface roughness. This talk presents a sharp-diffusive interface computational method for simulating multiphysics processes in metal AM, focusing on better handling the gas-metal interface, where metal AM physics mainly occurs. The framework consists of two components. The first is a mixed interface-capturing/interface tracking method to explicitly track the gas-metal interface topological changes without mesh motion or remeshing. The second is an enriched immersed boundary method (EIBM) to impose the critical flow, heat, and phase transition Neumann BCs, which are enforced in a smeared manner in current AM models, on the gas-metal inter-face with strong property discontinuity.

I will demonstrate how the developed model elucidates the fundamental metal AM physics (e.g., melt pool dynamics, keyhole instability, and powder spattering) and predicts critical part quality-related quantities (e.g., defect and surface roughness). The proposed framework’s accuracy is assessed by thoroughly comparing the simulated results against experimental measurements from NIST and Argonne National Laboratory using in-situ high-speed, high-energy x-ray imaging. I will also report other important quantities that experiments cannot measure to show the framework's predictive capability.

Mechanics and modeling of pavement structures and materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

VARIABILITY IN COMPACTION OF ASPHALT MIXTURES--EXPERIMENTAL INVESTIGATION AND PROBABILISTIC MODELING

Tianhao Yan[1], Jia-Liang Le[2], Mugurel Turos[2] and Mihai Marasteanu[2]*

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ABSTRACT

Compaction of asphalt mixtures is a crucial step in pavement construction. One primary concern related to compaction is its variability, which influences the uniformity of field density and, consequently, the overall quality of asphalt pavements. The present paper investigates the variability in asphalt mixture compaction through a combination of experiments and probabilistic modeling. In the experimental study, laboratory gyratory compaction is employed to characterize the compaction behavior of mixtures. The standard deviation of 12 replicates is calculated to evaluate the compaction variability for a particular mixture. Experiments are conducted on mixtures with different aggregate sizes and specimens of different heights to investigate the effects of aggregate and specimen sizes on compaction variability. The results show that larger specimen sizes decrease compaction variability, whereas larger aggregate sizes increase compaction variability. A mechanistic-based probabilistic model is developed for gyratory compaction to provide theoretical insights and explanations for the experimental observations. The model captures the inherent randomness of asphalt mixtures by simulating the spatial distribution of density as a Gaussian random field. The aggregate size is accounted for through the auto-correlation length of the random field. Variability in gyratory compaction process is modeled through Monte Carlo simulation. The simulated compaction process matches well the experimental results. Thus, the probabilistic model provides a theoretical explanation for the influences of specimen and aggregate sizes on compaction variability. This study enhanced our understanding of variability in the compaction of asphalt mixtures stemming from material heterogeneity and shed light on improving the reliability of asphalt pavement construction.

A PHYSICS-INFORMED PROBABILISTIC MACHINE LEARNING APPROACH FOR HIGH-COMPACTABILITY ASPHALT MIX DESIGN

Tianhao Yan[1], Yuxiang Wan[2], Mugurel Turos[2], Qizhi He[2], Jia-Liang Le[2] and Mihai Marasteanu[2]*

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ABSTRACT

Due to the physical complexity of asphalt mixtures, traditional asphalt mix design methods have relied heavily on empirical rules and trial-and-error, leading to a time-consuming design process and sub-optimal outcomes. To address these challenges, this paper introduces a physics-informed probabilistic machine learning framework that correlates material composition with the mechanical performance of asphalt mixtures. Our focus in this study is on applying this framework to optimize the compaction performance of asphalt mixtures. A physics-informed neural network (PINN) is employed, integrating the physical law for asphalt mixture compaction into the machine learning framework to enhance accuracy and rationality of predictions. A Bayesian Neural Network (BNN) is employed in combination with the PINN to quantify prediction uncertainties arising from the lack of data and inherent variability in the mechanical behavior of the material. The proposed machine learning model is trained and validated using material composition and laboratory gyratory compaction data obtained from a wide variety of previous mix designs. Results demonstrate the model's accuracy and its ability to capture prediction uncertainties, suggesting its potential application for designing and optimizing asphalt mixtures to improve compaction and field density. The proposed physics-informed probabilistic machine learning framework has promising potential to facilitate asphalt mix design practices.

BIM-BASED CONDITION ASSESSMENT AND BIM-FEM INTERCONNECTION FOR BRIDGES

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ABSTRACT

Infrastructure structures undergo a lengthy replacement cycle for components, which pose challenges in timely repairs and replacements. Therefore, it is crucial to establish a proper maintenance plan and develop efficient bridge history data based on the digitization of past and present maintenance information. The lack of integration in existing maintenance data hampers accurate condition assessments. To address these issues, ongoing attempts are being made to integrate and manage maintenance data based on Building Information Modeling (BIM). Efficient construction of maintenance data using BIM requires technology that allows visual confirmation of inspection data and the identification of damage location and size. In this study, an algorithm is proposed to extract damages from exterior damage images and generate a BIM mapped with these images, which enables automatic past and present condition assessments of a bridge including bridge components. Furthermore, to enhance interoperability between BIM and structural analysis, an algorithm is suggested to convert the BIM into finite element model with nodes and elements, incorporating material and sectional properties. The numerical analysis model, created based on the linked information, undergoes an analysis according to predefined damage scenarios. The results of the numerical analysis are then updated into the BIM. Subsequently, a condition rating assessment is conducted based on the updated damage information. This approach establishes a comprehensive history of bridge inspection and diagnosis data, which facilitate efficient maintenance and aids in the prevention of future damage.

Advances and applications of elasticity within applied mechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

THE GENERAL EQUILIBRIUM OF ELASTIC LAYERED SYSTEMS (GELS), AN OPEN-SOURCE IMPLEMENTATION IN PYTHON

David Yang[*1]

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ABSTRACT

Hankel Transforms of the biharmonic operator on a potential function are used to solve for the stresses and displacements in an elastic body under an axisymmetric load using cylindrical coordinates. The potential function of a fourth order partial differential equation reduces to a transformed second order ordinary differential equation with repeated roots. Four constant coefficients are determined from the boundary conditions. Solving the multiple elastic layer problem requires finding the four constant coefficients for each layer at each value of the Hankel transform variable. This implementation follows the solution as documented in Crawford, Hopkins and Smith, Theoretical Relationships Between Moduli for Soil Layers Beneath Concrete Pavements.

The one-layer solution requires finding only two constant coefficients from the boundary conditions and can be solved analytically for a normal uniform, circular surface load. Substituting the two constant coefficients into the Inverse Hankel Transforms to get the stresses and displacements, solutions in integrals of Bessel functions of the first kind, order zero and one are found. The Laplace Transforms of those Bessel functions matches the solutions of Boussinesq and Egorov, as documented in Harr, Foundations of Theoretical Soil Mechanics.

This implementation will be used to plot the stresses and displacements of an elastic layered system with layer thickness as a variable and the subgrade modulus as a variable under a multiple wheeled vehicle.

The origin of this implementation is from the University of Illinois, Urbana-Champaign, Multiple Wheel Elastic Layer Program (MWELP), from the early 1970s.

Multiscale behavior of damage and healing mechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

A LOCALIZING GRADIENT DAMAGE MODEL FOR THE DYNAMIC FRACTURE OF QUASI-BRITTLE MATERIALS AND ITS SIMPLE IMPLEMENTATION IN ABAQUS

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ABSTRACT

This presentation focuses on the dynamic fracture of quasi-brittle materials such as concrete and ceramics under different loading rates. With a view towards an ease of implementation, a simple form of damage model is considered with the necessary constitutive relations, to adequately capture the dynamic fracture responses under mixed mode loading conditions. Specifically, an energetic split into tensile and compressive components enabled the imposition of damage descriptors only on the former, to avoid spurious compression induced damage in mixed mode dynamic fracture phenomenon. Moreover, a history-dependent dynamic increase factor is introduced to capture the rate dependent behavior accurately, without inducing numerical instabilities. The numerical solutions are regularized via the localizing gradient enhancement to give sharp damage profiles resembling the development of macroscopic cracks. Finally, to facilitate an ease of implementation in the commercial software ABAQUS, the class of built-in thermal-mechanical elements is utilized, together with the VUMAT-VUMATHT subroutines. Validation of the model's capabilities is demonstrated through the Compact Tension Test and the Kalthoff-Winkler Test, underscoring its potential to accurately model the rate-dependent effect in dynamic mixed mode fracture.

References

Wang, J., L. H. Poh, and X. Guo. 2023. “Localizing gradient damage model based on a decomposition of elastic strain energy density.” Engineering Fracture Mechanics, 279: 109032. https://doi.org/10.1016/j.engfracmech.2022.109032.

Physics informed machine learning (PIML) for mechanics of porous media
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

OPERATOR LEARNING FOR SOLVING PDE FORWARD AND INVERSE PROBLEMS

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ABSTRACT

Learning operators between infinitely dimensional spaces is an important learning task arising in wide applications in machine learning, data science, mathematical modeling and simulations, etc. This talk introduces a new discretization-invariant operator learning approach based on data-driven kernels for sparsity via deep learning. Compared to existing methods, our approach achieves attractive accuracy in solving forward and inverse problems, prediction problems, and signal processing problems with zero-shot generalization, i.e., networks trained with a fixed data structure can be applied to heterogeneous data structures without expensive re-training. Under mild conditions, quantitative generalization error will be provided to understand operator learning in the sense of non-parametric estimation.

Structural identification and damage detection
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

QUANTIFYING NON-UNIQUENESS IN MODEL UPDATING AND DAMAGE DETECTION FOLLOWING A BAYESIAN APPROACH

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ABSTRACT

Model updating aims at providing accurate models to capture actual dynamic behaviors of structures based on experimental data. The updated models can then be used for revealing possible structural damage information. Uncertainties always exist in model updating due to incomplete information, i.e., unknown measurement noise and modeling errors because of imperfect modeling assumptions. These uncertainties usually cause the problem of non-uniqueness or local identifiability, i.e., multiple equivalent models can fit the experimental data almost the same well. Locating all these equivalent models in a high-dimensional parameter space is a challenging task. Moreover, including all of them for representing the target structure needs a theoretical basis. This work employs a Bayesian probabilistic framework for model updating, so that the uncertainties can be quantified, and thus all the equivalent models can be considered naturally. An parameter space-search algorithm is proposed to systematically locate all the equivalent models. Damage detection for a problem with multiple equivalent models using the tranditional method is not possible because there will be multiple models for both the undamged and damaged structure, and the one-to-one correspondence for calculating stiffness reduction is not straightforward. A new probabilistic framework for damage detection for locally identifiable problems is proposed. A transmission tower under laboratory conditions with limited modal parameters was used to verified the proposed method.

SIMULTANEOUS PROPAGATION OF HYDRAULIC FRACTURES FROM MULTIPLE PERFORATION CLUSTERS IN LAYERED TIGHT RESERVOIRS: NON-PLANAR THREE-DIMENSIONAL MODELLING

Lei Yang[1]*

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ABSTRACT

A hydromechanical coupled finite-discrete element method, which considers the non-planar three-dimensional growth, pressure continuity along the horizontal well, dynamic flow rate distributions among clusters, perforation friction, and fracturing fluid leakage, is employed to simulate the simultaneous growth of hydraulic fractures from an array of five perforation clusters in tight reservoirs interbedded with alternating stiff and soft layers. The simulation results highlight that the stress shadow induced by the non-planar propagation of the outmost hydraulic fractures stops the planar growth of the interior and middle hydraulic fractures and causes uneven fracturing fluid distribution among perforation clusters. The results demonstrate that the generated fracture pattern in the stage becomes more symmetric overall with the decreasing modulus of the soft layers. As the soft layer's modulus decreases, the total fracture height decreases significantly, but the local fracture aperture distribution increases, which leads to the reduction of total fracture area and leak-off volume of fracturing fluid as well as the increase of total fracture volume.It is also found that the adjustment of pumping rate is more effective than using nonuniform cluster spacing in promoting the simultaneous hydraulic-fracture growth in layered tight reservoirs.

IN-CONTEXT OPERATOR LEARNING WITH DATA PROMPTS FOR DIFFERENTIAL EQUATION PROBLEMS

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[1]University of California, Los Angeles

ABSTRACT

We introduce the paradigm of “in-context operator learning” and the corresponding model “In-Context Operator Networks” to simultaneously learn operators from the prompted data and apply it to new questions during the inference stage, without any weight update. Existing methods are limited to using a neural network to approximate a specific equation solution or a specific operator, requiring retraining when switching to a new problem with different equations. By training a single neural network as an operator learner, rather than a solution/operator approximator, we can not only get rid of retraining (even fine-tuning) the neural network for new problems but also leverage the commonalities shared across operators so that only a few examples in the prompt are needed when learning a new operator. Our numerical results show the capability of a single neural network as a few-shot operator learner for a diversified type of differential equation problems, including forward and inverse problems of ordinary differential equations, partial differential equations, and mean-field control problems, and also show that it can generalize its learning capability to operators beyond the training distribution.

Reference: https://www.pnas.org/doi/10.1073/pnas.2310142120

HYDRATION MECHANISM OF CEMENT PASTES WITH THE ADDITION OF DRY ICE THROUGH ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

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ABSTRACT

The addition of dry ice as an admixture to cement pastes has many advantages such as improving the compressive strength and sequestration of CO2. However, its effect on the hydration mechanism of cement pastes is still unknown and will be investigated using electrochemical impedance spectroscopy (EIS) in this paper. Based on the linear correlation of cumulative hydration heat from the isothermal calorimetry test and the logarithm of high-frequency resistivity, a modified Knudson equation is derived. Corresponding hydration kinetic parameters are calculated by applying the boundary nucleation and growth (BNG) theory and kinetics model including Avrami, geometrical contraction, and diffusion equations. The boundary area per unit volume (O_v^B) for the control specimen and specimens with 0.2 % and 0.5 % cement weight dry ice addition is 0.1171, 0.1250, and 0.1562 respectively indicating that the dry ice addition increases the surface area of the nucleation process. In addition, the results show that the Avrami equation for monitoring the nucleation process is limited. Regarding the hydration curves, the transition from the nucleation and growth (NG) stage to the interaction of phase boundaries (I) stage is delayed by adding dry ice to the mixture.

Advances in computer vision, deep learning and artificial intelligence for structural health monitoring and inspections
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DEEP LEARNING-BASED STRUCTURAL HEALTH MONITORING THROUGH THE INFUSION OF OPTICAL PHOTOS AND VIBRATION DATA

Saleh Al-Qudah[1] *and Mijia Yang**[1]

[1]*North Dakota State University*

ABSTRACT

This paper reports an investigation of deep learning techniques in structural damage identification that can overcome the limitations of traditional visual inspection. First, a vibration-based deep learning model is established to locate the damage in a beam and a truss structure. Then an optical photo-based model is established and used to classify different defects. Based on the satisfactory outcomes of these two models, a new structural health monitoring technique is proposed through the infusion of optical photos and vibration data. Vibration signals and true structural images for a truss are used to demonstrate the capability of the proposed method. It was found that the infusion of vibration data and optical photos can enhance damage identification significantly and overcome incomplete vibration signals or blurred optical photo inputs.

Mechanics and physics of granular materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

CONSTITUTIVE MODELING OF THE RATE-DEPENDENCY OF SAND DURING FLOWSLIDES

Ming Yang[1] and Giuseppe Buscarnera[1]*

[1]Northwestern University

ABSTRACT

A recently established multiscale framework coupling a sliding consolidation model with a local solver based on the discrete element method (DEM) suggests that the dynamics of flowslide runout in loose sand depends on two macroscale effects regulated by the shear rate: (i) the increased friction coefficient; (ii) the enhanced dilation. This contribution aims to develop a rate-dependent constitutive model capturing these behaviors observed in multiscale simulations. While the conventional viscoplasticity formulation of Perzyna-type, following the conceptual structure of Bingham model that adds a dashpot parallel to the plastic slider, effectively models the reduced runout distance, it is unable to reflect the rate-dependent nature of the friction coefficient (often referred to as mu(I) rheology), as seen both in experiments and DEM simulations of granular flow. To address this limitation, we propose an alternative conceptual structure reminiscent of an extended Kelvin-Voigt model. In this structure, both the spring and plastic slider are positioned in parallel to the viscous damper. This arrangement necessitates the partition of the total stress tensor into solid and rheological stress components. The solid stress corresponds to the standard effective stress of rate-independent plasticity models, and thus regulates the deformation of the spring and the plastic slider. The rheological stress is rate-dependent and obtained through the viscous damper, where the deviatoric part is collinear with the deviatoric strain rate, and the volumetric part is derived through thermodynamics, collectively giving rise to a compressible mu(I) rheology. The proposed constitutive model is shown to generate accurate simulation results under both drained and undrained simple shear simulations across a arrange of strain rates. Furthermore, it successfully reproduces the flowslide runout distance retrieved in DEM simulations and primarily regulated by the strain rate dependence of the material properties during the dynamic runout stage.

Origami/kirigami inspired structures and metamaterials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ORIGAMI VIA INSTABILITY

Yi Yang[1], Helen Read[1], David Melancon[2] and Katia Bertoldi[1]*

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ABSTRACT

Cylindrical shell structures made from soft materials undergo large deformations as pressurized. When subjected to a vacuum, these structures display a reversible buckling instability that mimics the kinematics of Kresling origami. In this study, we demonstrate that precise control of the geometry of thin-walled cylindrical shells leads to the emergence of distinct post-buckling deformation modes, including contraction, twisting, and bending. Leveraging these instability-driven deformations, we construct soft actuators capable of complex multimodal movements. The proposed design strategy is applied in both air and water, enabling soft manipulators that delicately pick up objects such as a fruit and a seashell using a simple vacuum.

Characterization and modeling of physical processes in porous materials across scales
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MICROPOROMECHANICS OF NON-ISOTROPIC INTERACTIONS AMONG PORES AND SOLID MATRIX

Yifan Yang[1], Dawei Xue[1] and Giuseppe Buscarnera[1]*

[1]Northwestern University

ABSTRACT

Non-isotropic interactions among primary and secondary minerals play a crucial role in subsurface geo-storage, including carbon sequestration enacted by mineralization reactions. To understand the role of such mineral transformations at the macroscopic scale of porous continua, an augmented poromechanical framework is developed based on the classical Biot's theory, thus focusing on the effect of isotropic stress-deformation effects stemming from the pores of the matrix. Applying micromechanics principles, the role of the stiffness ratio of both in-pore and matrix constituents is quantified by resolving explicitly the effect of the constitutive tensors of each unit and ensuring thermodynamic consistency. Casted in this form, it is shown that the framework can be coupled with thermal and chemical effects, i.e., two essential driving mechanisms in subsurface fluid storage operations. Furthermore, it is shown that by using an Eshelby elastic solution in conjunction with multiple types of homogenization schemes it is possible to specialize the macroscale constitutive law to non-isotropic interactions between the matrix and idealized ellipsoidal pores, either individual (dilute scheme) or interacting (Mori-Tanaka-Benveniste scheme). In this augmented framework the pore-scale loadings induced by physicochemical effects into the pores become equivalent to eigenstrains stemming from the secondary minerals produced by mineralization reactions. With this driving mechanism, a series of parametric analyses are carried out. It is finally shown that the mechanical properties of the secondary minerals significantly affect the magnitude of porosity change, matrix volumetric strain, and the potential for crack opening, all effects that are predicted to be nonlinear and that will play a role in the success of subsurface storage operations.

Data-driven methods and research for physical testing in structural engineering
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MECHANICS-INFORMED DATA MODEL PREDICTION OF STEEL COLUMN STRENGTH CONSIDERING BUCKLING DEFORMATION AND INITIAL GEOMETRIC IMPERFECTIONS

Kai Chen[1], Cem Bartu Cevik[2], Cristopher Moen[3], Yile Wang[1], Yuchen Yang[1] and Zhidong Zhang[4]*

[1]Johns Hopkins University
[2]Robert College
[3]RunToSolve LLC
[4]University of Virginia

ABSTRACT

An XGBoost decision tree data model is trained and tested. The training data is generated by solving random samples of the classical ordinary differential equation for a simply-supported steel column with an initial sweep imperfection combined with a first yield stress interaction failure criterion consistent with the Perry-Robertson equation. Model accuracy is evaluated for different decision tree general, booster, and task parameters with the goal of establishing a model protocol that can be generally followed for mechanics-informed data models. Input parameter importance (column length, initial imperfection magnitude, and column section properties) is also quantified.

PMC - General Session
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ROLE OF SUBSTRATE ROUGHNESS IN SOIL DESICCATION CRACKING

Yuhan Yang[1], Chao Zhang[1], Linyun Gou[1], Renpeng Chen[1] and Yi Dong[2]*

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ABSTRACT

Soil desiccation crack is ubiquitous in nature, yet the physics of its initiation and propagation is still under debate. Existing researches imply that the desiccation phenomenon is an outcome of highly coupled processes in multiphase media under multiple fields of mechanics, hydraulics, and even thermals. Such coupled physics occurring at multiple types of interfaces in soil gives rise to unprecedented complexities in soil desiccation. Here, an experimental attempt is made to uncover the role of substrate roughness, a commonly recognized key factor, in the soil desiccation process. The substrate roughness is deliberately fabricated by 3D printing, whereas the thickness of soil sample and environmental humidity are controlled to eliminate the effects of large hydraulic gradient. Four types of soils with varying expansibilities are desiccated on substrates with varying roughness. It reveals that: (1) soil desiccation crack evolution can be conceived as a competing process between the shear failure of the interface, i.e., slippage of the soil-substrate interface, and the tensile failure of soil, i.e., crack propagation, in minimizing the total energy of drying soil; (2) substrate roughness alters the failure mode and shear strength of soil-substrate interface and its sensitivity to moisture, thereby it regulates the pattern of how soil crack propagates in soil with varying expansibilities upon drying; (3) soil expansibility is recognized as a key factor governing the crack-initiation point in addition to the widely recognized air-entry, and flaws in soil are the sources for the crack angle of 120° and bimodal crack angle distribution.

Uncertainty quantification and machine learning for design, optimization, and inference in multiscale systems
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MACHINE LEARNING FOR STATISTICAL MODELING OF FIBER-REINFORCED COMPOSITES DELAMINATION

Zhengtao Yao[1], Philippe Hawi[1], Venkat Aitharaju[2], Jay Mahishi[2] and Roger Ghanem[1]*

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ABSTRACT

Delamination in fiber-reinforced composites is a critical area of study due to its impact on the structural integrity and life of composite materials. Achieving perfect contact between layers during the manufacturing process is challenging with any discrepancy potentially inducing delamination. This phenomenon can severely compromise mechanical performance and lead to catastrophic failures in critical applications such as aerospace and automotive industries. The mechanical behavior of a carbon-resin composite material under Mode I and Mode II fracture for use as automotive battery enclosure is explored in this work. Deep learning models are applied to understand and predict the delamination behavior of composites using Representative Volume Elements (RVE), a widely used conceptual and numerical device to explore the constitutive relationship of materials while soliciting information from their subscale, by describing the behavior at one material point of a physical device while homogenizing the local behavior over finer scales.

Specifically, a four-layer-stacked RVE is created and canonical tests of Modes I and II failure are set. Geometrical features within each RVE (e.g. radius ratio and volume fraction) are specified as random variables with Beta distributions. Material properties within each RVE, including strength and stiffness of the resin, tows, and cohesive layers are specified as independent Beta-distributed random variables. A total of 2000 RVE simulations, with samples drawn from the above Beta-distributions, are conducted for laminae tearing (ZZ strain) and shearing (XZ strain), with tows in fixed tension and in compression strain load. Intermediate results such as stress history and energy history of the components are extracted and used for training the ML models. A quadrature failure envelope of the strain combination is captured, and it is found that tension RVE has a higher max strength combination and compression will cause deterioration of the delamination strength, in both ZZ and XZ directions.

PCA (Principal Components Analysis) is used to eliminate spurious discontinuities and accelerate predictions of the stress-strain curve via dimension reduction. It is worth noting that 10 principal components out of 100 contain 99% of the variance for six directions of stresses history. A good match between predictions and ground truth is found using PCE (Polynomials Chaos Expansion) and neural network as machine learning models, for delamination constitutive relationship, both in linear and nonlinear (deterioration) regime of the stress-strain curve. A user-defined subroutine is developed in LS-Dyna to explore the multiscale analysis using this method to verify its accuracy.

Plan the future: Innovations in advanced cementitious materials and sustainability
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

CONCEPTUAL DESIGN AND PRODUCTION OF LIGHTWEIGHT TWO-STAGE CONCRETE COMPOSITES

Fan Zheng[1] *and Hailong Ye**[1]

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ABSTRACT

With the development of building information modelling (BIM) and the increase in labour costs, modular integrated construction (MiC) which adopts the concept of factory assembly followed by on-site installation is a promising trend. For MiC projects, the application of lightweight concrete can increase the efficiency of transportation and lifting. Using lightweight aggregates to replace normal aggregate is a common strategy for designing lightweight concrete. However, the mechanical strength of concrete is compromised by the segregation and lower strength of lightweight aggregates. In this work, a lightweight concrete composite for structural applications was designed and produced. The concept of two-stage concrete was introduced for casting to prevent segregation of lightweight aggregates. A vacuum-assisted slurry infiltration setup was designed and assembled, in which the lightweight aggregates were preplaced in the mould and then the slurry was poured to fill the voids between the aggregates. Foam glass with a size range of 10-20 mm and a crushing strength around 10 MPa was used as lightweight aggregates to replace normal aggregates by different volume proportions. The slurry used was a lightweight ultra-high performance concrete (UHPC), which can reduce the composite density and compensate for the strength reduction caused by lightweight aggregates. By using different combinations of lightweight UHPC and lightweight aggregates, lightweight concrete composites with various strength grades can be designed. The proposed casting setup for lightweight two-stage concrete composite production at the element scale can be implemented in the prefabrication factory.

PMC - General Session
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

STATISTICAL EVALUATION OF GEOMETRICAL MICROVOID CHARACTERISTICS THAT INITIATE ULTRA LOW CYCLE FATIGUE FRACTURE

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ABSTRACT

Structural steel members and connections may experience ultra-low cycle fatigue (ULCF) loading during earthquakes. Field observations and laboratory tests of structural steel connections and full-scale steel structures indicate ductile fracture as the fracture-initiating mechanism under ULCF loading. Ductile fracture under ULCF is dependent on the strain amplitude which is usually large, the number of cycles which is less than 100, and the evolving stress state and total plastic strain. Stress triaxiality and Lode parameter are the dimensionless quantities explored by researchers to quantify the stress state. Microvoid coalescence initiates ductile fracture and the geometric void configuration at the instance of ULCF fracture is not explored yet. The present study aims to geometrically characterize the microvoids experimentally at the instance of fatigue fracture and determine their relationship with the quantities that describe the state of stress and strain in the fracture specimens.

In the present study, ULCF tests were conducted on axisymmetrically notched ASTM A992 structural steel specimens to achieve a wide range of high-stress triaxialities. High-resolution micrographs of the fracture surface of the test specimens were obtained using a scanning electron microscope. Subsequently, representative regions with 75µm × 75µm projected surface areas were randomly chosen on each micrograph and 25 microvoids were sampled from each of the representative areas. Statistical analysis was performed on the microvoid sizes extracted from the micrographs. To understand the relationship between stress triaxiality, plastic strain, and microvoid geometrical features, micrographs were extracted across the diameter of the fracture specimens. Non-linear finite element analysis was performed on the notched specimens to obtain the variation of stress triaxiality and equivalent plastic strain across the cross-section of the fracture surface. The relationship between the experimentally obtained microvoid geometrical features, stress triaxiality, and equivalent plastic strain will be discussed in the talk.

Mechanics and physics of granular materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

NUMERICAL INVESTIGATION OF GRAIN SIZE SEGREGATION MECHANISMS IN DEBRIS FLOWS

Fan Yi[12] and Fernando Garcia[1]*

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[2]*Tianjin University*

ABSTRACT

Post-wildfire debris flows are increasing in frequency due to ongoing climate change and its effects on rainfall intensities and wildfire potential. The probability, runout path, and inundation depths of debris flow hazards are modeled well through various numerical means, but modeling of these effects typically requires homogenizing the solid debris into a single phase. The solid debris can range in size from fine silts to large boulders, the latter of which pose a unique impact hazard not associated with the finer debris or fluid phase. The boulders can destroy structures, block evacuation routes, and alter debris runout paths. Over long runout distances, the boulders segregate from the rest of the viscous debris to form a boulder-rich debris front. Coarse-grained lateral levees form as the advancing finer-grained debris pushes the coarser debris aside. Understanding of the mechanisms behind grain size segregation and lateral levee formation during debris flows is crucial for comprehending the full mechanics of debris flow runout. To accurately forecast the runout paths and potential impact energy of boulders, the boulders must be modeled as a discontinuous granular system. This study achieves the latter using the discrete element method to simulate the processes of grain size segregation and levee formation using two distinct particle types with different grain sizes. The simulation results are validated against physical experiments with different proportions of fine and coarse grains. The coarsest particles translate in a helical motion relative to the front of the flow due to velocity gradients along the depth and width of the debris. This motion is hypothesized from physical experiments but can be fully quantified via discrete element simulations. Factors such as grain size and shape distribution, basal boundary conditions, and interparticle contact properties are further explored to show the principal dependencies of grain size segregation. The roughness of the flume surface and the fluency of finer particles are shown to play the most pivotal roles in levee formation. The initial point of levee deposition and width of the coarse-grained levees are observed to be highly sensitive to the volume fraction of the coarse and fine grains. Further assessments will focus on evaluating how the scalability of grain size influences the motion of debris flows and how the simulation approach may be applicable to realistic terrain associated with debris flow case histories.

Structural identification and damage detection
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ESTIMATION OF UNKNOWN PARAMETERS AND HIDDEN PHYSICS WITH ADAPTIVE BASIS FUNCTION AND SUCCESSIVE CONVEX APPROXIMATION

Letian Yi[1], Siyuan Yang[1], Ying Cui[1] and Zhilu Lai[1]*

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ABSTRACT

Continuous spatiotemporal dynamic models are often represented by differential equations (ODEs or PDEs). In previous research, various surrogate models have been proposed to simultaneously fit measured data and satisfy differential equations to approximate the response process, including global and local function methods. However, the global function methods, typically represented by physics-informed neural networks (PINN), lack the necessary repeatability and robustness due to their sensitivity to initial parameter values and noise. On the other hand, the local function methods, represented by various basis functions, struggle to accurately fit data which have unevenly distributed geometric features, affecting the accuracy of parameter estimation and high-order derivatives. The proposed method adaptively adjusts basis functions according to the data feature distribution, thereby accurately approximating the solution of the differential equation. Additionally, the successive convex approximation (SCA) algorithm is introduced to solve nonconvex optimization problems arising from nonlinear differential equations, theoretically guaranteeing solution convergence. The proposed method is shown to effectively estimate parameters, approximate solutions, and solutions' high-order derivatives of various differential equations with considerable precision. The method combines scientific theories with detailed data information in a systematic manner to deduce the properties of the process from observed data.

Computational statistics for natural hazards engineering: Advances in uncertainty quantification, surrogate modeling, and dimension reduction for performance-based design of structures and systems
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

GAUSSIAN PROCESS SURROGATE MODELING OF WIND PRESSURE STATISTICS OF TWO ADJACENT BUILDINGS

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ABSTRACT

Urban cities are vulnerable to the impact of dynamic wind effects. In predicting the wind load applied to the building surfaces, it is important to consider properly the interference from the surrounding building environment. In particular, such inter-building wind interference effect is often investigated through a series of wind tunnel experiments, repeated for different arrangements of buildings, their geometries, and wind directions. To interpolate the wind tunnel experiment database and to provide the outcome of unseen experiments, this research develops a surrogate model that can predict the wind-induced interference effect. We used the physical wind tunnel experiment dataset developed and shared by Tokyo Polytechnic University (TPU) to train a surrogate model, consisting of spatiotemporal pressure patterns measured at the surface of a building model located adjacent to another tall building model. In particular, a Gaussian process (GP) surrogate model is developed to predict the time-aggregated statistics - mean, standard deviation, and peaks of pressure coefficients - across the building surface for different building arrangements, building heights, and wind directions. To deal with high-dimensional output quantities of interest (representing the spatial pattern of each pressure statistic), the principal component analysis-based dimension reduction technique is introduced and coupled with GP formulation, and the results are compared with alternative GP formulations without dimension reduction. Different calibration objective functions and correlation kernel choices are investigated with numerical results. The unique discussion points include consideration of periodicity in the wind direction, selection of optimal GP calibration objective functions compromising among multiple output quantities, selection of appropriate validation metrics for multiple outputs with varying scales, average and quantile performances, and effect of different underlying noise levels in the observation dataset. Additionally, adaptive Design of Experiments (DoE) strategies are applied to guide the sequential design of wind tunnel tests, aiming at identifying the aerodynamically favorable and unfavorable wind scenarios and maximizing the information to train a surrogate model from a limited number of wind tunnel tests.

Failure and function in structural stability applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

BUCKLIPHILIA TO THE RESCUE: PROTOTYPES FOR BUCKLING-DRIVEN SHADING SOLUTIONS

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ABSTRACT

Buckling and structural instabilities are generally considered as concepts to design against, rather than design for them. In numerous cases, erroneous assumptions or negligence of instability effects, have led to detrimental results and failures in structural engineering. As new computational tools able to perform nonlinear analyses become widespread, the emergence of new engineered materials has created new pathways, where a particular instability can be designed for, as an aspect of the multifunctionality of the particular structure. This concept is not new, it has already been considered for passive control of adaptive systems in the aerospace and automotive industries, in the form of Morphing Structures[1]. This has been further explored by Reis[2], defining this trend for designing for instabilities as “Buckliphilia”, in other words “buckling-“ or “instability-friendly” designs. In this work we explore different applications where “buckliphilia” emerges as a low energy solution to a particular problem and particularly through the investigation of prototypes of different strut configurations with buckling driven control for shading. Inspired by a reduced mechanical model for temperature adaptable facades[3] and the postbuckling behaviour of 3D printed struts[4], this contribution concludes by showing how buckliphilia prototypes tackling a particular problem could be used in a Stability class as a practical example for designing for instabilities.

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PMC - General Session
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EFFECT OF DIFFERENT STRUCTURAL CHARACTERISTICS ON SEISMIC FRAGILITY CURVES OF REINFORCED CONCRETE FRAME BUILDINGS

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ABSTRACT

Multi-story reinforced concrete (RC) buildings, constituting the majority of building stock in Turkey, were significantly affected by numerous major earthquake events in the past, including the latest sequence of earthquakes that occurred in Kahramanmaras, Turkey on February 6th, 2023. The extensive damage and total collapse of these buildings can be attributed to inadequate designs that do not comply with seismic codes, low material quality, and poor construction practices. Meanwhile, aging effects such as corrosion in RC members can degrade section capacities and alter global dynamic characteristics of the structure, ultimately increasing its seismic vulnerability over its lifetime. The aim of this study is to assess the impact of various structural characteristics on the seismic fragility curves of typical RC frame buildings. Within this scope, a parametric study is conducted on building frames with different number of stories, considering both high-code and low-code seismic designs, increments in concrete compressive strength and different levels of steel reinforcement corrosion. The finite element models of the frames are subjected to nonlinear time-history analyses, and resulting demands are used to develop seismic fragility curves for each combination of building features. At the end of the study, critical structural features influencing seismic fragility are identified, and a discussion on determining the optimum service life of these types of buildings is presented. The fragility curves developed in this study can be utilized in frameworks for estimating regional damage and losses under given earthquake scenarios.

Discrete models for the simulation of infrastructure materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MULTI-PHYSICS LATTICE DISCRETE PARTICLE MODEL (M-LDPM) FOR THE COUPLING OF DIFFUSION PROCESSES AND FRACTURE

Hao Yin[1], Mohammed Alnaggar[2], Giovanni Di Luzio[3], Weixin Li[4], Madura Pathirage[5], Lei Shen[6], Matthew Treomner[7], Lifu Yang[8] and Gianluca Cusatis[1]*

[1]Northwestern University
[2]Oak Ridge National Laboratory
[3]Politecnico di Milano
[4]Apple, Inc.
[5]University of New Mexico
[6]Hohai University
[7]Cusatis Computational Services, Inc.
[8]Hunan University

ABSTRACT

In this study, a Multiphysics-Lattice Discrete Particle Model (M-LDPM) framework with the application for coupled fracture-pore flow problems has been formulated. The M-LDPM framework involves fully coupled dual lattice systems, named the LDPM tessellation and the Flow Lattice Element (FLE) network. The LDPM governing equations are revisited and imposed with the influence of the fluid pore pressure. The Flow Lattice Model (FLM) governing equations for pore pressure flow have been derived through the mass conservation laws within both uncracked and cracked volumes. The numerical implementation of LDPM utilizes the Abaqus explicit dynamic user element subroutine VUEL, while the FLM implementation utilizes the Abaqus implicit transient user subroutine UEL. The data communication in M-LDPM coupling is implemented using the operating system Interprocess Communication (IPC) mechanism which exchanges information between the two Abaqus solvers that run as two independent processes. The M-LDPM framework enables seamless coupling of the mechanical and diffusion/flow behavior of the material at the aggregate scale. As a result, the variation of conductivity and permeability induced by fracturing processes can be simulated by formulating the transport constitutive laws of the flow elements as functions of local crack conditions. The validity of the M-LDPM framework is tested by comparing the numerical simulation results with analytical solutions of classical benchmarks in poromechanics.

4M (modeling of multiphysics-multiscale-multifunctional) engineering materials and structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

SINGUM MODELING OF MULTISCALE AND MULTIPHYSICAL BEHAVIOR OF LATTICE-BASED MATERIALS

*Huiming Yin**[1]

[1]*Columbia University*

ABSTRACT

Lattice materials formed by springs or bonds with connection nodes are common in 3D printing metamaterials or crystal structures. When short-range interactions between the nodes are considered, the effective material behavior depends on the interaction nature and the lattice structure. The recently developed singum model transfers the force-displacement relationship of the springs in the lattice to the stress-strain relationship in the continuum particle of singum, and provides the analytical form of tangential elasticity. When a pre-stress exists in the lattice, the stiffness tensor significantly changes due to the effect of the configurational stress. The anisotropy and asymmetry of the stiffness tensor for some unique lattice structures are demonstrated. The singum model can be extended to multiphysical behavior of lattice-based materials. The effective thermal conductivity of a granular lattice is predicted.

Assessing human-infrastructure interactions and their performance
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

VISION-BASED MONITORING FOR PEDESTRIAN SUSPENTION BRIDGES

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ABSTRACT

Recently, numbers of long span pedestrian suspension bridges have been constructed worldwide. While recent tragedies regarding pedestrian suspension bridges have shown how these bridges can wreak havoc on the society, the current practice for maintenance for the pedestrian suspension bridges are not being done efficiently. This study presents a new vision-based structural health monitoring system for pedestrian suspension bridges. The proposed system estimates the location and the magnitude of the pedestrian load, as well as the dynamic response of the pedestrian bridges by utilizing artificial intelligence and computer vision techniques. A simulation-based validation test and on-site validation tests was conducted to verify the performance of the proposed system.

Advances in modeling wind and its effects on the built environment
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EXPERIMENTAL INVESTIGATION OF HIGHLY TURBULENT WIND FIELD EFFECTS ON SPHERICAL DEBRIS FLIGHT

Shaopeng Li[1], Kimia Yousefi Anarak[2], Ryan Catarelli[1], Yanlin Guo[2], Kurtis Gurley[1] and John van de Lindt[2]*

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ABSTRACT

A highly turbulent wind field can significantly impact the flight trajectories of windborne debris and hence the risk of damage to building envelopes. Faithfully simulating complex debris flight behaviors in a realistic three-dimensional (3D) turbulent wind field using numerical simulations can be very challenging due to both accuracy/efficiency issues. Wind tunnel testing may be a viable approach to investigate the windborne debris flight characteristics. Existing wind tunnel studies on debris flight usually fail to properly scale the debris and accurately generate a highly turbulent wind field that reflects realistic urban wind conditions. In addition, the impacts of the source building (where debris is released) and the target building (where debris hits) on the wind field and debris flight trajectory have not been quantitively studied in the existing literature. This study systematically investigates the wind field impact on spherical debris flight in the Boundary Layer Wind Tunnel at the University of Florida. The building and debris are scaled to properly represent the full-scale prototype. To accurately model turbulence scale and intensity, an array of actively controlled fans are utilized to recover the low-frequency energy deficit in wind turbulence resulting from conventional passive devices. High-speed cameras equipped with computer vision techniques track the 3D flight trajectory of properly scaled debris in a realistic turbulent wind field. The impacts of low-frequency wind turbulence, wake flow past source building, and distorted flow before target building are discussed in detail. This study provides valuable data for revealing the mechanisms of complex debris flight behaviors in highly turbulent winds and validating numerical models for windborne debris flight.

Topology optimization: From algorithmic developments to applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

NEURAL NETWORKS WITH KERNEL-WEIGHTED CORRECTIVE RESIDUALS FOR INVERSE DESIGN

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ABSTRACT

Topology optimization is a challenging inverse problem as it is high-dimensional and usually constrained by partial differential equations (PDEs) and additional inequalities. Recently, Physics-Informed Neural Networks (PINNs) have been employed to simplify this process, but they struggle to manage all design requirements and their effectiveness largely depends on network configuration. To address these challenges, we leverage neural networks (NNs) with kernel-weighted Corrective Residuals (CoRes) for topology optimization. We have recently developed NN-CoRes to integrate the strengths of kernel methods and deep NNs. In this presentation, we show that they greatly help in (1) satisfying equality constraints in the design problem, and (2) simplifying the inverse design by decreasing the sensitivity of NNs to factors such as random initialization, architecture type, and choice of optimizer.

Molecular scale modeling and experimentation
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

BRUCITE CARBONATION: MOLECULAR INSIGHTS AND SUSTAINABLE CARBON CAPTURE

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ABSTRACT

Mineral carbonation as a viable strategy for carbon capture and storage (CCS) has gained considerable attention in recent years. Often found in serpentine deposits and hydrothermal veins, brucite ($Mg(OH)_2$) has emerged as a promising solution for carbon mineralization due to its abundance and potential for sequestering carbon dioxide. This study employs molecular dynamics simulations and enhanced sampling methods to delve into the intricacies of brucite carbonation by studying crucial aspects of this process such as bicarbonate formation, magnesium carbonate nucleation, and water exchange around magnesium atoms.

Investigating the formation of bicarbonate species reveals the complex details of the initial stages of carbonation, providing fundamental insights that are crucial for optimizing carbon capture processes. This process is influenced by kinetic barriers related to the activation energy required for the conversion of dissolved carbon dioxide into bicarbonate ions. The lack of an appropriate reactive Force Field has been an obstacle for achieving this goal. Bicarbonate, as an intermediate product, eventually transforms into stable carbonate minerals through various mineralization reactions. These carbonate minerals effectively trap and immobilize CO_2 by preventing its release into the atmosphere. Also, by scrutinizing the magnesium carbonate formation through the formation of a stable nucleus, we aim to contribute to the development of strategies for controlled mineralization, enhancing the technological efficiency of brucite-based carbon capture.

Furthermore, in trying to understand the dynamic behavior of water molecules surrounding magnesium atoms, the water exchange dynamics have been studied to explain the role of hydration in the carbonation process. The coordination of water molecules and their stability in the hydration shell affect the overall reactivity of magnesium hydroxide with carbon dioxide, influencing the kinetics and thermodynamics of the reaction. This knowledge would be instrumental in designing interventions to accelerate or decelerate the carbonation rate as needed for practical applications.

The importance of this research extends beyond the realms of fundamental science. Harnessing brucite carbonation for carbon capture not only addresses the global challenge of mitigating anthropogenic CO_2 emissions but also holds the potential to revolutionize the landscape of sustainable energy technologies. The scalability and cost-effectiveness of brucite, coupled with the insights gained from our molecular-level investigations, position this mineral as a cornerstone in the development of environmentally friendly CCS solutions.

Probabilistic assessment, data-driven inference and optimization for decision-making under uncertainty
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ENHANCING THE RESILIENCE OF LARGE-SCALE INFRASTRUCTURE NETWORKS USING GNN-ENHANCED DEEP REINFORCEMENT LEARNING

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[2]Princeton University

ABSTRACT

Infrastructure systems play a critical role in ensuring socio-economic prosperity and public safety. As such, it is imperative to rapidly restore damaged infrastructure systems in the aftermath of disruptions. During restoration management, decision-makers in infrastructure systems face the challenge of optimizing the dispatch of multiple repair crews and network flow over the restoration horizon. However, this task is an NP-hard problem that cannot be solved exactly using polynomial time algorithms.

This study develops a GGN-enhanced deep reinforcement learning framework to optimize the resilience of large-scale infrastructure networks. This model integrates graph neural network (GNN) into deep reinforcement learning (GNN-DRL): the GNN model is designed to learn a more effective embedding of the infrastructure network while the DRL model is trained to optimize repair decisions and network flow. Specifically, the GNN model encodes essential information about the network using inputs such as topology and performance of service nodes and then outputs learned characteristics of the networks, including a more effective representation of node and link features as well as network state evolution. These learned characteristics are then fed into the DRL model to improve its performance, which enables the search for optimal solutions in a prohibitively large action space.

While several studies have explored the application of DRL to enhance the resilience of infrastructure networks, most of these efforts have oversimplified crucial aspects of the restoration problem. For example, some have simplified the dispatch of repair crew or omitted the design of the optimal network flow, thereby constraining their practicality. To better mimic real-world distribution networks, our model incorporates Kirchhoff's current law for nodes (flow conservation) and voltage law for links (linear scaling of flow with potential drop). Notably, the proposed model also addresses the dispatch of multiple repair crews at the same time step. Furthermore, our model considers the relative significance of service nodes and accommodates changes in user demand following disruptions. To handle large-scale networks, the model is trained using both small synthetic and real-world infrastructure networks and then applied to various large-scale application scenarios.

To validate the GNN-DRL model, extensive simulations are conducted across various real-world and synthetic large-scale infrastructure networks affected by multiple hazard scenarios. The proposed model is compared against multiple heuristic optimization approaches (e.g., greedy algorithms, genetic algorithms, and simulated annealing) in terms of solution quality and efficiency. Results indicate that the GNN-DRL model outperforms alternative approaches, leading to higher system resilience.

NUMERICAL SIMULATION OF FLOW, SETTING, AND HARDENING OF 3D PRINTED CONCRETE

Ke Yu[1], Bahar Ayhan[1], Erol Lale[1], Matthew Treomner[1] and Gianluca Cusatis[1]*

[1]Northwestern University

ABSTRACT

3D printed concrete as an innovative construction technology has been increasingly used for intricate and customized structural designs. This requires an improved comprehension of the material properties' transition from the flow stage to solidification in concrete. The primary objective of this study is to simulate the various phases of 3D-printed concrete, including the flow, setting, and hardening stages, and validate the modeling method. The fresh concrete was simulated using smoothed particle hydrodynamics (SPH) coupled with the discrete element method (DEM). DEM was employed to represent the aggregate, capturing the movements of discrete particles, while the SPH was utilized to simulate the cement paste, modeling the continuous property of the concrete mixture. After the concrete setting, the lattice discrete particle model (LDPM) was used to model the failure behavior of concrete at the meso-scale. The concrete setting process, which depicts the transition of concrete from a viscous fluid to a solid state, was also simulated. The evolution of material properties during the concrete setting was provided by experimental tests. The entire simulation was performed in Project Chrono which is an open-source multi-physics engine. The simulation was validated by comparing the numerical results with the experimental data of real 3D printed concrete.

Structural identification and damage detection
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

IDENTIFICATION OF STRUCTURAL PROPERTIES FROM LVD MEASUREMENT OF A STEEL RAILWAY BRIDGE

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ABSTRACT

Steel railway bridges are durable transportation infrastructure systems designed by allowable fatigue life, strength, and deformation response. With proper maintenance, their lifespan can be more than 100 years. During the long period of their service life, their deterioration rate needs to be updated by field data to avoid sudden failures from happening. The objective of this research is to present an approach to extract the structural properties (mass, damping, stiffness) of steel railway bridges using a single-point laser doppler vibrometry (LDV) from field data. A more-than-75-year-old steel railway bridge was measured by a portable continuous wave infrared (CWIR) LDV system at the midspan of the bridge to collect the dynamic displacement responses with (forced vibration) and without (free vibration) the train loading. Issues with modal coupling in the spectrum response were addressed before extracting damping ratio from the time-domain displacement response. A bounding approach was developed to estimate the ranges of fundamental mass, damping, and stiffness values of the bridge, as well as the train speed, to address the uncertainties in locomotive and passenger car weights.

Advances in modeling of material damage and fracture
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

REMOTE TRANSIENT ELECTROMAGNETIC SCATTERING RESPONSE OF FRACTAL CRACKS IN MULTI-PHASE BRITTLE MATERIALS

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ABSTRACT

Cracking in multi-phase brittle materials such as Portland cement concrete is the main cause for jeopardizing the integrity, durability, and sustainability of the materials. Due to the heterogeneity of the materials, formation and development of cracks are manifested by three-dimensional irregular and complex shapes that may be described by fractal geometry. While surface cracks on brittle materials can be visually detected and mapped, their subsurface geometry is very challenging to be measured without destructive means. In this presentation, we present a simulation study on the transient electromagnetic (EM) scattering response of fractal cracks in brittle materials, using the finite difference time domain (FDTD) method. Different dimensions of Julia set fractals were introduced to a two-dimensional (2D) material model simulated by lossless dielectrics. A modulated Gaussian incident signal (point source) with a center frequency ranging from 8GHz to 18GHz was used to illuminate the cracked model. EM scattering response was collected by a circular antenna array in the simulation domain to study the radar cross section (RCS) (or radiation pattern) of each fractal crack. From our simulation work, it is found that the RCS of each fractal crack is sensitive to crack development, suggesting the importance of polar difference in the application and data interpretation of EM sensors (e.g., ground-penetrating radar and synthetic aperture radar) on concrete structures.

PARTITION MODELING AND HETEROGENEOUS SOLUTION OF 3D TRAIN-TRACK-BRIDGE COUPLED SYSTEM SUBJECTED TO EARTHQUAKE EXCITATIONS

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ABSTRACT

As the computational complexity of practical engineering systems under environmental effects increases significantly, such as a 3D train-track-bridge coupled time-varying system considering random wheel-rail contact and earthquake excitations, how to efficiently and accurately solve and evaluate complex dynamic systems has garnered considerable attention. This study proposed a non-iterative partitioned computational method with the energy conservation property to efficiently resolve complex dynamic problems. The proposed method is composed of two computational modules: multi-partitioned structural analyzers and an interface solver, providing a modular solution for time-variant systems. A nonlinear time-varying mechanical model for the earthquake-TTB system, as an illustrated three-subsystem example, is established to demonstrate the method. Specifically, a 3D multi-train model considering a single train with 42 DOF and nonlinear wheel-track forces is constructed as a train subsystem. The rail-sleeper-ballast system is established as a track subsystem, and a typical multi-span continuous prestressed concrete simply supported beam bridge is built as a bridge subsystem. Track irregularities are regarded as stochastic excitations within the system, and 120 practical ground motion records with different combinations of magnitude-source-to-site distance (M-R) and earthquake intensity characteristics are selected as the external excitations. The application of the proposed method to address the partitioned system involves a comparative evaluation against various methods, including iterative approaches, highlighting its superior performance. Meanwhile, diverse scenarios regarding various combinations of vehicle speeds and track irregularity levels are defined in the analysis. Numerous nonlinear time-history analyses are conducted to evaluate the system comprehensively. Results indicate that the proposed method eliminates the necessity for time-variant matrix formation and the utilization of complex iterative procedures in partitioned computations, which significantly improves computational efficiency.

Cementitious materials: Experiments and modeling across the scales
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

CEMCAT: CEMENTITIOUS MATERIALS CATALOGUE WITH THEIR COMPOSITIONS, PROPERTIES, SYNTHESIS AND CHARACTERIZATION METHODS, AND APPLICATIONS

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ABSTRACT

Cement is an essential construction material with complex chemistry and properties. The research advancements aim to enhance concrete's mechanical, chemical, and thermal properties. Sustainability is another aspect of cementitious materials that govern their practical applications. Researchers have reported numerous compositions of cementitious materials, their microstructure, properties, applications, synthesis and characterization methods through rigorous simulations and experiments. Some databases exist, like the NCSU concrete database1, the NIST database2, and a recent database3 of 279 compositions of supplementary cementitious materials collected from 107 research papers. In this work, we propose CemCat, a database of cementitious materials created through automated literature mining methods built on MatSciBERT (the world's first materials domain language model) and DiSCoMaT (graph neural network-based pipeline from extraction materials compositions from research paper tables). CemCat currently has ~20,000 compositions obtained from the research papers using DiSCoMaT. There are ~40,000 papers in the database from which various named entities like materials, synthesis and characterization methods, properties, and applications are extracted using MatSciBERT. This database aims to provide information about existing materials, their applications, properties, and manufacturing methods, allowing researchers and industries to gain insights into making sustainable concrete. In the presentation, we will discuss the information extraction tools (MatSciBERT and DiSCoMaT) used in this work and provide statistics about different aspects of the database, which will be helpful for the advancement of research for construction materials.

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Design and additive manufacturing of engineering structures and materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

THERMO-CHEMO-RHEOLOGICAL MODELING OF DIRECT INK WRITING BASED ON FRONTAL POLYMERIZATION

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ABSTRACT

Conventional manufacturing processes for thermoset polymers and composites typically involve continuous heating in an autoclave, which is an energy intensive and costly procedure. In recent years, frontal polymerization direct ink writing (FP-DIW) has emerged as a promising technique for the freeform manufacturing of polymeric structures with minimal energy requirements and no post-processing [1]. FP leverages heat diffusion and an exothermic reaction to propagate a self-sustaining polymerization front that cures a liquid or gel monomer, such as dicyclopentadiene (DCPD), into a solidified polymer. This technique is amenable to additive manufacturing by extruding a gel ink from a nozzle and utilizing FP to cure the material in its unsupported configuration. Of critical importance in this process is the effect of both mechanics and chemistry on the dimensional accuracy of the printed structure. The gel exhibits nonlinear viscoelastic properties as evidenced by shear thinning and die swell, and these properties evolve over time during the gelation process. The process parameters must be calibrated to ensure the extruded material cures before experiencing excessive deformations. Computational tools have recently been developed to predict the effect of process parameters on the dimensional accuracy of the printed part, accounting for both the rheology of the extruded material [2] and the solid-like behavior of the cured part [3]. In this talk, we first describe the thermo-chemo-rheological model that has been used to capture the effect of process parameters, material properties and environmental conditions on front propagation and the shape of axisymmetric structures printed through FP-DIW. We then discuss recent progress in implementing this model in 3D and the effect of rheological properties on the deformation of the extruded material. Lastly, we present on the application of FP-DIW to printing unidirectional carbon fiber tows and the multiphysics modeling approach used to study this process.

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Data-scarce modeling in engineering mechanics: Probabilistic learning, information maximization & transfer learning
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

CONSTRAINED COST-AWARE MULTI-FIDELITY BAYESIAN OPTIMIZATION

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ABSTRACT

Bayesian optimization (BO) is a widely used technique for finding materials with unprecedented properties. However, relying solely on expensive high-fidelity (HF) sources can inflate optimization expenses in complex scenarios. To address this challenge and incorporate known and unknown constraints, we introduce a novel constrained cost-aware multi-fidelity BO (C2-MFBO) framework with a few novelties. Firstly, it uses manifold-embedded Gaussian process (GP) for emulation which handles mixed input spaces and models source-dependent noise and global trends. Secondly, it leverages a composite acquisition function (AF) that quantifies the information value of high- and low-fidelity sources differently and also accommodates source-dependent constraints. Through analytical and real-world examples, we will demonstrate the benefits of our approach which is publicly available via the GP+ package in Python.

FEATHER-INSPIRED ARCHITECTED MATERIALS WITH SHAPE MEMORY

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ABSTRACT

The keratinous materials in the calamus section of avian feather shafts exhibit outstanding mechanical properties, providing strength, toughness, and inherent lightweight characteristics crucial for supporting aerodynamic functions during flight. Recent reports have also confirmed the role of shape memory properties in feather shafts, playing a crucial role in preventing permanent damage that might compromise the structural integrity of the feathers. In our study, we focus into the mechanisms driving these shape memory properties using mechanics and simple models, with a specific focus on the synergistic interplay between the matrix—an amorphous phase that absorbs water and undergoes inelastic deformation under severe stress—and the fibers—intermediate keratin filaments rich in crystalline domains resilient to hydration. Our preliminary analysis emphasizes the role of matrix swelling and softening due to hydration. Building on these insights, we develop a simple design concept and establish a mathematical framework for crafting bioinspired shape memory architected materials. In this talk, I will explain the conceptual framework and how these principles are put into practice through architected materials in such a way that these materials can be used for morphing and/or actuation.

Mechanics of wood and wood-based materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

CHARACTERIZATION OF MECHANICAL PROPERTIES OF FIVE HOT-PRESSED LIGNINS EXTRACTED FROM DIFFERENT FEEDSTOCKS BY MICROMECHANICS-GUIDED NANOINDENTATION

Luis Zelaya-Lainez[1], Michael Schwaighofer[1], Markus Königsberger[1], Markus Lukacevic[1], Sebastian Serna-Loaiza[1], Michael Harasek[1], Anton Friedl[1] and Josef Füssl[1]*

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ABSTRACT

Lignin is a pivotal constituent of wood, ranking as the second most prevalent organic material globally. The escalating demand for sustainable and renewable resources propels the exploration of innovative applications for technical lignins, such as their integration as a matrix in bio-composites. Nevertheless, the pursuit of modeling these bio-composites hinges on precisely identifying lignin's mechanical properties, which remains relatively elusive. Complicating matters further is that technical lignins sourced from lignocellulosic materials exhibit notable disparities in their chemical composition, size, cross-linking, and functional groups. These variations arise from discrepancies in the raw materials and the isolation methods employed, including the pulping process and subsequent isolation and purification techniques. Hence, it becomes imperative to address these disparities when evaluating and understanding the mechanical characteristics of lignin. To tackle this challenge, our study examines five distinct hot-pressed lignins derived through diverse extraction processes from varying feedstocks. The assessment employs microscopy-aided grid nanoindentation, aiming to unravel the nuanced mechanical properties of these lignins. Through such meticulous investigation, we endeavor to contribute valuable insights that will aid in comprehending the intricate interplay between lignin's structural variations and its mechanical behavior. The derived mechanical properties exhibit a robust correlation with the porosity observed in the lignin specimens. This correlation finds an apt description through the Mori-Tanaka homogenization scheme within the framework of continuum micromechanics. Employing this micromechanical model, we conducted a reverse calculation to determine the stiffness of "solid" lignin devoid of pore influence, revealing Young's modulus of 7.12 GPa. The noteworthy alignment between the micromechanics model and the experimentally measured indentation modulus validates that the indentation modulus of solid lignin remains consistent across all five variants. Remarkably, this consistency holds irrespective of the extraction process or the specific feedstock employed.

Topology optimization: From algorithmic developments to applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

OPTIMIZATION OF VOIDED POST TENSIONED SLABS

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ABSTRACT

Concrete, a major contributor to global CO2 emissions, necessitates enhanced structural efficiency to mitigate environmental impact. Given that a substantial portion of concrete in buildings resides in floor slabs, reducing concrete volume in slabs emerges as a central strategy to curtail overall consumption. Voided slabs, featuring embedded void elements, demonstrate increased structural efficiency by minimizing concrete consumption. Recent advancements highlight the superior performance of post-tensioned (PT) voided slabs, leveraging reduced cross-sectional voided areas to require fewer cables compared to solid PT slabs.

Structural optimization is a design tool that converts a structural design problem to a constrained minimization problem, solves it with mathematical programming tools, and has been shown to improve the efficiency of the structural design. However, existing studies typically focus on either optimization of voided slabs or PT slabs. Thus, in this study we present combined optimization of voided PT slabs, where the parametrization includes both geometrically rich cable layout and the voids distribution. Moreover, we extend existing studies on PT optimization in slabs by adding the number of tendons in each cable within a gradient-based framework. The results show notable savings both in concrete and in PT steel, resulting in significantly lower carbon footprint than traditional structural slab systems.

Computational fluid dynamics (CFD) and fluid-structure interaction (FSI): Method development and applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

COMPRESSIBLE EULER FLOW COMPUTATIONS USING THE SHIFTED BOUNDARY METHOD

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ABSTRACT

In this talk we present the Shifted Boundary Method (SBM) for inviscid compressible flow computations in complex geometries. The Shifted Boundary Method belongs to the class of unfitted finite element methods. It reformulates the original boundary value problem over a surrogate (approximate) computational domain that does not have to be conformal to the true geometry; and accuracy is maintained by modifying the original boundary condition using Taylor expansions. Because SBM avoids integration over cut cells, it does not suffer from small time-step issues and allows efficient explicit time integration. Previously the SBM has been applied to solve the Poisson equations, Stokes flow equations, and viscous incompressible flows on complex domains, and in this talk we detail the derivation of SBM for more complex wave structures for Euler equations.

In addition to the general methodology derivation and numerical verification, we also discuss the advantages the SBM offers in avoiding spurious numerical artifacts in two scenarios: (a) when curved boundaries are represented by body-fitted polygonal approximations and (b) when the Kutta condition needs to be imposed in immersed simulations of airfoils.

Uncertainty characterization and propagation in complex nonlinear structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DATA-DRIVEN PROJECTION PURSUIT FOR UNCERTAINTY QUANTIFICATION AND SURROGATE MODELING IN HIGH-DIMENSIONAL AND DEPENDENT PARAMETER SPACES

Xiaoshu Zeng[1] and Roger Ghanem[1]*

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ABSTRACT

Uncertainty quantification (UQ) and prediction for complex engineering systems pose two significant challenges: the curse of dimensionality stemming from high-dimensional parameter spaces and the necessity to handle dependent parameter spaces. While Polynomial Chaos Expansions (PCE) present a robust approach, their effectiveness relies on independent standard Gaussian variables. In our prior work, we introduced Projection Pursuit Adaptation (PPA) to efficiently construct PCE models, addressing the curse of dimensionality even with limited Monte Carlo (MC) data. This study targets the challenge of dependent parameter spaces through a data-driven approach. PCE relies on independence, and in scenarios with modest dimensions, methods like the Rosenblatt transformation can decouple dependent variables. However, this method necessitates joint distribution information, posing challenges in high-dimensional spaces. To address this, we propose using multivariate Regular Vine (R-vine) copulas to capture dependency structures within parameters. Subsequently, the Rosenblatt transformation enables bidirectional transformations between independent and dependent Gaussian samples. The R-vine copulas are integrated with the PPA method, establishing a unified framework for constructing optimally reduced PCE models tailored for high-dimensional problems with dependent parameter spaces. Our proposed methodology showcases remarkable accuracy in both UQ and prediction tasks, with the constructed PCE serving effectively as a surrogate model for machine learning regression. The efficiency of our approach is verified through applications of a borehole model and a space structure.

A CASE STUDY OF DETECTING SEGMENT JOINTS IN SHIELD TUNNELS USING RANGE IMAGES

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ABSTRACT

With the rapid pace of urbanization, subways that are typically housed in underground shield tunnels have gained popularity as an environmentally friendly mode of travel. Shield tunnels, as a prefabricated assembly structure, are prone to excessive deformation under the earth pressure over time. Therefore, it is crucial to monitor the structural deformation of subway tunnels to assess their reliability and guide their maintenance. High-precision technologies, such as Light Detection and Ranging (LiDAR) scanning for point clouds and close-range photogrammetry for high-definition images of a tunnel's internal surface, are currently employed to obtain operation and maintenance data. However, shield tunnels exhibit a structural weakness due to their segment joints. The rigid body movement of the joints contributes significantly more to the overall tunnel convergent deformation than the deformation of segments, but is often neglected. While the circumferential joints between adjacent segment rings can be easily identified from images via computer vision techniques, it is difficult to detect the longitudinal joints within the same ring due to interference of power pipelines or other facilities. Accurate localization of these joints within a ring is essential for calculating their rigid body movement from the point cloud. To address this issue, this study proposes a deep learning-based method for detecting segment joints within a ring using range images. A rotary scanning device with a depth sensor collected numerous range images of an operational shield tunnel's inner surface. These images were then analyzed to differentiate the depth features of segment joints from other installed facilities and equipment. A deep neural network based on the Encoder-Decoder architecture was constructed, with the collected range images as inputs, and the joint segmented images as outputs. The proposed method was compared to edge detection methods and traditional image segmentation models using the same dataset to assess accuracy and effectiveness. The results indicate that using range images for segment joint localization improves accuracy through enhanced feature extraction based on depth information. Additionally, by comparing to the traditional image segmentation method, the proposed deep learning model demonstrates better robustness in detecting longitudinal segment joints in real-world shield tunnels.

Keywords: Shield tunnel deformation; Segment joint detection; Range image; Deep learning; Encoder-decoder

Mechanics and physics of granular materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

EFFECTIVE STRESS AND POROELASTICITY THEORY FOR UNSATURATED SOILS INCORPORATING ADSORPTION AND CAPILLARITY

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ABSTRACT

Adsorption and capillarity, in the order of high free energy to low, are the two soil–water interaction mechanisms controlling the hydro-mechanical behaviour of soils. Yet most of the poroelasticity theories of soil are based on capillarity only, leading to misrepresentations of hydro-mechanical behaviour in the low free energy regime beyond vaporisation. This inability is reasoned to be caused by two major limitations in the existing theories: missing interparticle attraction energy and incomplete definition of adsorption-induced pore-water pressure. A poroelasticity theory is formulated to incorporate the two soil–water interaction mechanisms, and the transition between them – that is, condensation/vaporisation, by expanding the classical three-phase mixture system to a four-phase mixture system with adsorptive water as an additional phase. An interparticle attractive stress is identified as one of the key sources for deformation and strength of soils induced by adsorption and is implemented in the poroelasticity theory. A recent breakthrough concept of soil sorptive potential is utilised to establish the physical link between adsorption-induced pore-water pressure and matric suction. The proposed poroelasticity theory can be reduced to several previous theories when interparticle attractive stress is ignored. The new theory is used to derive the effective stress equation for variably saturated soil by identifying energy-conjugated pairs. The derived effective stress equation leads to Zhang and Lu’s unified effective stress equation, and can be reduced to Bishop’s effective stress equation when only the capillary mechanism is considered and to Terzaghi’s effective stress equation when a saturated condition is imposed. The derived effective stress equation is experimentally validated for a variety of soil in the full matric suction range, substantiating the validity and accuracy of the poroelasticity theory for soil under variably saturated conditions.

Advances in computer vision, deep learning and artificial intelligence for structural health monitoring and inspections
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

TRAINING ACCURATE COMPUTER VISION BASED INFRASTRUCTURE DEFECT DETECTION MODEL UNDER ANNOTATION NOISE

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[2]Hong Kong University of Science and Technology

ABSTRACT

CV-based infrastructure defect detection is a highly data-centric application, where the labeling quality can be of crucial concern. Pixel-level labeling for image segmentation is a time-consuming but necessary job, often outsourced to third-party services. In the labeling process, noisy labels are unavoidable given that each annotator may have a different understanding of crack boundaries and even produce 'lazy' labels that contain large background areas. These noisy labels then confuse the model in the training process, by ignoring some complex crack geometry. In this talk, we will present a noisy learning framework to deliver accurate CV crack detection models under the influence of noisy labels. The effectiveness of the framework will be demonstrated on industrial-level real-world dataset created in the Hong Kong community.

SYNERGISTIC EFFECTS OF NANOPARTICLE GEOMETRIC SHAPE AND POST CURING ON CARBON-BASED NANOPARTICLE REINFORCED EPOXY NANOCOMPOSITES: CHARACTERIZATION, MICROSTRUCTURE AND ADHESION PROPERTIES

Dawei Zhang[1], Ying Huang[1] and Xingyu Wang[1]*

[1]North Dakota State University

ABSTRACT

Incorporating carbon-based nanoparticles and optimizing curing conditions are commonly recognized as two effective approaches of pursuing enhanced properties of epoxy nanocomposites. This study specifically explores the synergistic effects of nanoparticle geometric shape and post curing on carbon-based nanoparticle reinforced epoxy nanocomposites. Nanodiamonds (NDs), carbon nanotubes (CNTs), and graphenes (GNPs) with spherical, cylindrical, and planar geometric shapes are integrated in the epoxy matrix as 0-D, 1-D, and 2-D nanofillers, respectively. Epoxy nanocomposites with and without post curing are synthesized for each nanofiller and evaluated based on dispersion quality, viscosity, microstructure, and mechanical properties. Experimental results indicate that ND reinforced epoxy nanocomposites exhibit a more homogeneous nanoparticle dispersion, lower viscosity, reduced porosity, stronger adhesion properties, while CNT and GNP reinforced epoxy nanocomposites achieve higher tensile and shear strengths. In addition, post curing is proved to be effective in reducing porosity and improving mechanical properties of epoxy nanocomposites, but its effect becomes less pronounced with the addition of nanoparticles.

ENERGY RENORMALIZATION FOR TEMPERATURE TRANSFERABLE COARSE-GRAINING OF SILICONE POLYMER

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[2]Iowa State University

ABSTRACT

The bottom-up prediction of thermodynamic and mechanical behaviors of polymeric materials based on molecular dynamics (MD) simulation is of critical importance in polymer physics. Although the atomistically informed coarse-grained (CG) model can access greater spatiotemporal scales and retain essential chemical specificity, the temperature-transferable CG model is still a big challenge and hinders widespread application of this technique. Herein, we use silicone polymer, i.e., polydimethylsiloxane (PDMS), having a very low chain rigidity as a model system, combined with an energy-renormalization (ER) approach, to systematically develop a temperature-transferable CG model. Specifically, by introducing temperature-dependent ER factors to renormalize the effective distance and cohesive energy parameters, the developed CG model faithfully preserved the dynamics, mechanical and conformational behaviors compared with target all-atomistic (AA) model from glassy to melt regimes, which was further validated by experimental data. With the developed CG model featuring tremendously improved computational efficiency, we systematically explore the influences of cohesive interaction strength and temperature on the dynamical heterogeneity and mechanical response of polymers, where we observed consistent trends with other linear polymers with varying chain rigidity and monomeric structures. This study serves as an extension of our proposed ER approach of developing temperature transferable CG models with diverse segmental structures, highlighting the critical role of cohesive interaction strength on CG modeling of polymer dynamics and thermomechanical behaviors.

4M (modeling of multiphysics-multiscale-multifunctional) engineering materials and structures
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DYNAMIC RESPONSES OF VISCOELASTIC COMPOSITE BEAMS WITH SPHERICAL INCLUSIONS UNDER HARMONIC EXCITATION

Jinming Zhang[1], Chunlin Wu[2] and Huiming Yin[1]*

[1]*Columbia University*
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ABSTRACT

This study explores the influence of particles in a viscoelastic particulate composite beam on its energy dissipation and natural frequency when subjected to external excitations. Utilizing Eshelby's equivalent inclusion method (EIM), the material mismatch is simulated by eigenstrains. The effects of particle interactions and boundaries are investigated through the inclusion-based boundary element method (iBEM). Spatial variations of eigenstrains are expressed in the polynomial-form based on the Taylor series expansions. The local stress field changing with time is solved through the domain and boundary integrals of the Green's function. Numerical case studies illustrate the effect of particles on the energy dissipation and natural frequency shifts of the viscoelastic system. A comparative analysis with a matrix without inclusions provides a comprehensive understanding of the complexities introduced by inhomogeneities. The findings highlight the substantial impact of microstructures on the dynamic behavior of the material, offering critical insights for design and analysis of composite materials under vibration environments.

Advances in regional hazard modeling and risk assessment
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

TC-SINDY: A DATA-DRIVEN FRAMEWORK TO DISCOVER PHYSICS-BASED TROPICAL CYCLONE TRACK AND INTENSITY MODELS

Xi Zhong[1], Wenjun Jiang[1] and Jize Zhang[1]*

[1]Hong Kong University of Science and Technology

ABSTRACT

Due to the limited historical tropical cyclones (TCs) records, it is critical to understand TC risk using large sets of synthesized TC events from statistics-based or physics-based TC track and intensity models. Physics-based models are often regarded as practically advantageous for their unique capability to represent basic physical principles and incorporate climate change impacts. However, formulating the physics-based models are not easy, commonly obtained by simple empirical formulas with inadequate performance.

Here, we present a simple yet powerful framework that distills physics-based TC models from historical TC data. By treating TC evolutions as dynamical systems, we discover the TC track and intensity governing equations from historical TC and environmental data via the Sparse Identification of Nonlinear Dynamics (SINDy) approach. Results show that our proposed TC-SINDy approach is able to identify parsimonious yet effective physics-based TC models. The identified models were applied to simulate TCs in the Western North Pacific (WNP) basin and the North Atlantic (NA) basin. Comparing against alternative models, our models agree better with historical records in terms of the prevailing tracks, the maximum sustained wind, and the statistics of key parameters (including the annual occurrence rate, translation speed, minimum approaching distance, and maximum tangential wind speed) along various kilo posts. Then, our proposed models were coupled with a widely used parametric wind field to obtain the probabilistic distribution of the surface wind. The results show that the estimated distributions are close to the historical histograms in two basins. Overall, it can be concluded that the proposed method presents a general data-driven framework for discovering physics-based TC models, enabling accurate TC simulations while reserving the capacity to accommodate the varying climate.

TC-DIFFUSION: A DEEP MARKOV-CHAIN TROPICAL CYCLONE SIMULATION MODEL WITH APPLICATION TO TYPHOON WIND HAZARD ANALYSIS

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ABSTRACT

This paper introduces TC-Diffusion, a novel Markov-chain tropical cyclone full track simulation method. TC-Diffusion utilizes the recently proposed diffusion deep generative model, to enhance the accuracy and effectiveness of the Markov-chain simulations. Leveraging diffusion's exceptional capability to process high-dimensional inputs and conditions, our proposed TC movement and intensity model can effectively consider the TC state spatial heterogeneity without the need for segmentation or clustering. Additionally, it can incorporate various TC states to inform the simulated track and intensity change over the next 6 hours, all while maintaining the complexity of the underlying probability models. A synthetic 74-year TC dataset is simulated from the proposed full track simulation method to be compared against the historical TCs in the China Meteorological Administration (CMA) dataset. The results indicate that the developed model had strong performance in terms of matching the spatial distributions and landfalling statistics of historical TCs, even in TC-sparse regions. The developed full track model is ultimately combined with a parametric wind field to estimate wind hazards along the China southeastern coastline. Estimated design wind speed in multiple return periods generally agrees with those in the design code and alternative full-track methods. To summarize, this study allows for the application of diffusion models to enhance the simulation of TCs using a Markov-chain approach.

ESTIMATING BUILDING-LEVEL SEISMIC DAMAGE THROUGH SELECTED STRUCTURAL MEMBERS

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ABSTRACT

Advanced sensors, such as distributed fiber optic sensors, enable accurate damage measurements at the structural member level following disasters like earthquakes. However, it is often unfeasible to place sensors on every structural member within a building. Due to the complex and uncertain nature of building-level damage patterns, a criterion for selecting instrumented structural members is still lacking. This study introduces a novel probabilistic methodology for quantifying seismic damage, which utilizes information from selected members with sensor instrumentation (assuming known damage) to predict damage for the entire building. To demonstrate the framework, a reinforced concrete frame numerical model (based on the Van Nuys hotel) is employed, accounting for uncertainties in both material properties and input. We examine the physical damage evolution process for typical structural members and investigate damage correlations using a multi-output Gaussian process model. Based on this analysis, we propose an optimal selection procedure for instrumented structural members.

Computational geomechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

WAVE PROPAGATION PROPERTIES IN GRANULAR MEDIA: RELATING ELASTIC WAVES TO MECHANICAL SIGNATURES

Li Zhang[1] and Jun Yang[1]*

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ABSTRACT

Wave propagation in granular materials and their mechanical behaviors are intrinsically intertwined. Whether we can predict shear-induced signatures of granular soils (e.g., fabric anisotropy) based on wave propagation properties and, if yes, what relationship can be obtained possess practical importance. The analytical framework would be promising in geotechnical applications as the wave velocity can be measured both in the laboratory and in the field. Here, we present a robust grain-scale model to propagate elastic waves along three principal stress directions through dense and loose randomly-packed granular assemblies. The varying extent of fabric anisotropy is obtained under a spectrum of triaxial stress states. Comprising hundreds and thousands of spherical particles, long specimens bounded by periodic boundaries are created to eliminate the near-field effect that brings uncertainties in determining wave velocity. The results show that variations of the wave velocity exhibit a positive correlation with the change of mean effective stresses and coordination numbers. A marked finding is that: wave velocity varies significantly along different propagating and vibrating directions owing to the anisotropic distribution of inter-particle contacts within a granular assembly. Moreover, a linear relationship can be established between the wave velocity anisotropy and fabric anisotropy.

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Computational geomechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

COUPLED THMC MODEL-BASED PREDICTION OF HYDRAULIC FRACTURE GEOMETRY AND SIZE UNDER SELF-PROPPING PHASE-TRANSITION FRACTURING

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ABSTRACT

The coupling of thermal, hydraulic, mechanical, and chemical (THMC) fields occurring during realization of self-propping phase-transition fracturing technology (SPFT) differs from those observed under geothermal development and carbon dioxide storage conditions, making it difficult to clarify the hydraulic fracture propagation pattern under the SPTF multifield coupling conditions. Based on the SPFT parameters and the physical/chemical characteristics of the phase-transition fracturing fluid system (PFFS), this study elaborated a set of THMC multifield coupling models. The algorithm comprehensively combining the finite element method, discretized virtual internal bonds, and element partition method (FEM-DVIB-EPM) was proposed and verified on the case study. The results show that the FEM-DVIB-EPM coupling algorithm can reduce the difficulty and improve the solving efficiency. Conventional fracturing fluid is used to form fractures, then PFFS is ejected to prop fractures, and finally, the displacement fluid is injected to replace all PFFS into the reservoir, which is the best injection mode. The length of the hydraulic fracture increases with the increase in the amount and displacement of PFFS, and excessive displacement may lead to uncontrolled fracture height. Under the parameters of the cases in this paper, the fracture length is not much different after the amount of PFFS exceeds 130 m3. When the displacement is 5 m3/min, a longer fracture length can be obtained under the condition of limiting excessive extension of the fracture height. This work helps reveal the mechanism of hydraulic fracture propagation caused by SPFT and provides a basis for hydraulic fracturing technology and treatment parameter optimization.

Discrete models for the simulation of infrastructure materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DISCRETE MODELS OF CONCRETE HETEROGENEITY

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ABSTRACT

Concrete heterogeneity plays a large role in determining its fracture behavior. In particular, the presence of aggregate particles within the cement-based matrix influences fracture and other properties of interest. By explicitly representing aggregate particles and their mechanical interactions, Lattice Discrete Particle Models effectively capture the role of heterogeneity during fracture processes [1]. Other discrete mechanical models of concrete, including alternative particle-based lattice models, account for heterogeneity in other ways [2]. This research employs Voronoi-cell lattice models (VCLM) to understand the various forms of heterogeneity that can be present within discrete modeling frameworks. For elastic stress analyses, which underpin the modeling of fracture, conventional lattice models simulate elastic behavior in a macroscopic sense. In a local sense, however, spurious fluctuations in stress occur, which can be regarded as a form of heterogeneity. Although this notional form of heterogeneity may have utility, it depends on discretization geometry and size. As described by Asahina et al. [3], the VCLM can be rendered elastically uniform for arbitrary settings of the elastic constants. Heterogeneity can then be introduced in a controlled manner by mapping, for example, spatially correlated distributions of stiffness and strength onto the lattice structure. Whereas this approach is effective for elastic stress analyses, the modeling of fracture involves additional considerations. Since the fracture criteria are formulated in terms of vectorial stress measures, which is a common trait of discrete modeling approaches, an additional form of heterogeneity appears. Here, too, there is a dependence on discretization geometry. The relative significance of the aforementioned forms of heterogeneity is investigated through the analysis of concrete fracture under various forms of loading.

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Multi-fidelity methods and machine learning for uncertainty propagation, inference, and optimization
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MULTI-FIDELITY BAYESIAN OPTIMIZATION IN ENGINEERING DESIGN

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ABSTRACT

Resided at the intersection of multi-fidelity optimization (MFO) and Bayesian optimization (BO), MF BO has found a niche in solving expensive engineering design optimization problems, thanks to its advantages in incorporating physical and mathematical understandings of the problems, saving resources, addressing exploitation-exploration trade-off, considering uncertainty, and processing parallel computing. The increasing number of works dedicated to MF BO suggests the need for a comprehensive review of this advanced optimization technique. In this paper, we survey recent developments of two essential ingredients of MF BO: Gaussian process (GP) based MF surrogates and acquisition functions. We first categorize the existing MF modeling methods and MFO strategies to locate MF BO in a large family of surrogate-based optimization and MFO algorithms. We then exploit the common properties shared between the methods from each ingredient of MF BO to describe important GP-based MF surrogate models and review various acquisition functions. By doing so, we expect to provide a structured understanding of MF BO. Finally, we attempt to reveal important aspects that require further research for applications of MF BO in solving intricate yet important design optimization problems, including constrained optimization, high-dimensional optimization, optimization under uncertainty, and multi-objective optimization.

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Structural identification and damage detection
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

IDENTIFICATION OF CREEP DAMAGE IN STRUCTURAL SYSTEMS USING PHYSICS-INFORMED PARALLEL NEURAL NETWORKS

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ABSTRACT

The identification of creep damage is critical for predicting the service life and ensuring the safety of structural systems subjected to long-term stress and environmental conditions. Recently, it has been demonstrated that Physics-Informed Parallel Neural Networks (PIPNNs) can be applied successfully and accurately to solve the inverse problems for the identification of structural systems. In this research, a significant extension of the PIPNNs framework is developed and demonstrated, addressing the specific challenges of identifying creep damage in structural systems based on limited and noisy sensor data. In this framework, based on continuum damage mechanics, the creep damage is represented as a continuous state variable throughout the structure. The creep deformation process is governed by a system of ordinary differential equations (ODEs), including an evolution equation for the damage state variables and a constitutive equation characterizing material damage behavior. In its general form, the ODEs are able to consider the various states of creep damage, that is the primary, secondary, tertiary and failure. The PIPNNs framework integrates sensor data, the governing mechanics equations, the boundary conditions of the structural systems, and the ODEs governing the creep damage evolution into the loss function of the neural network (NN) architecture. Through minimizing the physics-informed loss function, the NNs parameters and unknown initial damage state variables can be estimated. With the trained NNs, the full state of the structural system and the evolution of creep damage can then be estimated. The accuracy and validity of the damage identification PIPNNs framework are demonstrated by comparing its results to those obtained from closed-form analytical expressions when available and otherwise, the solution of the Ritz method for various structural systems. These examples include a two-column system and a two-span continuous beam, considering both concrete and metal materials and their associated creep damage evolution equations. The results consistently demonstrate that the PIPNNs framework can accurately estimate the evolution of creep damage within the structural system as well as being able to reconstruct the full state of the system based on the limited and noisy sensor data. Furthermore, for the studied inverse problems, the suggested PIPNNs framework was observed to be robust with respect to noise levels in the sensor data.

Recent advances in hybrid simulation and real-time hybrid simulation
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DYNAMIC CHARACTERIZATION OF ARCHITECTED METAMATERIALS USING REAL-TIME HYBRID SIMULATION

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ABSTRACT

Architected metamaterials are an emerging class of materials with extraordinary properties that can be tailored to achieve specific objectives by customizing their microstructural configurations. Further, the growth of additive manufacturing has enabled 3D printing of complex microstructures and has further stoked interest in this area. Applications areas of such architected metamaterials include mechanical, thermal, electrical, chemical, optical, magnetic and numerous others.

In this study, we focus on characterizing the dynamic performance of architected metamaterials such as energy absorption and wave attenuation under low velocity impact. We consider both, auxetic and nonauxetic microstructures, and study their response under plane wave propagation. A parametric study is conducted to evaluate how different microstructures perform and how their properties may be tailored to maximize wave attenuation.

A key objective of this study is to enable the use of real-time hybrid simulation (RTHS) for studying the dynamic characteristics of architected materials. With RTHS, that part of the metamaterial domain that is subjected to impact and undergoes large deformations and damage is modelled physically and other parts of the domain that remain linear are modeled numerically. A single actuator transfer system is used to connect the physical and numerical subdomains using an in-house Linux-based real-time execution platform. This effort is ongoing and challenges with conducting such RTHS and lessons learned will be presented.

CROSS ENTROPY ADAPTIVE IMPORTANCE SAMPLING USING AN EXPRESSIVE NON-PARAMETRIC MIXTURE MODELING APPROACH

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ABSTRACT

Importance sampling is a pivotal technique for estimating failure probabilities in rare events, particularly in structural reliability analysis. IS efficiency highly depends on the quality of the chosen importance sampling density. Cross Entropy (CE) based Adaptive Importance Sampling (AIS) is recognized as an effective approach for identifying near-optimal sampling densities [1,2]. To advance CE-based AIS This study presents a new non-parametric Mixture model that aims to approximate the optimal IS proposal density. It combines the simplicity and parsimonious character of parametric approaches with the flexibility of non-parametric approach, and adapts the proposal based on failure sampling in the CE-guided manner. The resulting model underwent evaluation against a range of benchmark and engineering instances, and demonstrated superior performance in terms of efficiency and stability compared to current baselines. Analysis will be provided regarding the gain in IS performance.

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A NON-UNIFORM ADAPTIVE MODEL ORDER REDUCTION TECHNIQUE FOR MODELING COMPOSITE MATERIALS

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ABSTRACT

Computational modeling of composite materials under these extreme conditions, to achieve predictive analysis and design, is an important but challenging task. The challenges particularly come from capturing highly nonlinear behaviors at the microstructural scale and efficiently upscaling from material microstructures to structural components. Among the existing modeling techniques, reduced order modeling (ROM) has gained significant attention due to its ability to balance computational cost and efficiency. The eigendeformation-based reduced-order homogenization model (EHM) has proven to be effective in capturing inelastic responses of complex microstructures, which approximates the microscale problem with a much-reduced basis spanning over partitioned subdomains of the microstructures, where the response of each subdomain is assumed to be uniform. While EHM delivers a hierarchy of gradually refining ROMs ranging from low-fidelity-high-efficiency to high-fiddley-low-efficiency by increasing the number of subdomains (i.e., order of the ROM) used to partition the microstructure, a fixed partitioning of the microstructure is still challenging when involving highly complex geometries and nonlinear behaviors. Efforts have been made to enhance the efficiency of EHM through a Uniform Adaptive Reduced Order Modeling (UAROM) approach, where the simulation switches between a series of pre-defined gradually and uniformly refining ROMS, as the loading and the localization in subdomains continues. However, the ROM order increases substantially and it becomes hard to control since refining happens in all subdomains uniformly. This limitation restricts the flexibility of the method, hindering its applications in modeling highly complex damage initiation and propagation where adaptability and fine control are essential. To tackle these challenges, we propose the Non-uniform Adaptive Reduced Order Model (NUAROM), which draws inspiration from Adaptive Finite Element Methods (AFEMs). In contrast to the uniform approach, the NUAROM only selectively refines the subdomains that have localization reached a certain criterion, similar to the concept of mesh refining around propagating crack tip in AFEM. The applicability and accuracy of NUAROM are verified through numerical examples involving single or multiple inclusion particulate composite microstructures with phase continuum damage and/or cohesive interface damage.

Design and additive manufacturing of engineering structures and materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ALGORITHMIC ENCODING OF ADAPTIVE RESPONSES IN TEMPERATURE-SENSING MULTI-MATERIAL ARCHITECTURES

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ABSTRACT

We envision programmable matters that can alter their physical properties in desirable manners based on user input or autonomous sensing. This vision motivates the pursuit of mechanical metamaterials that interact with the environment in a programmable fashion. However, this has not been systematically achieved for soft metamaterials due to the highly nonlinear deformation and underdevelopment of rational design strategies. Here, we use computational morphogenesis and multi-material polymer 3D printing to systematically create soft metamaterials with arbitrarily programmable temperature-switchable nonlinear mechanical responses under large deformations. This is made possible by harnessing the distinct glass transition temperatures of different polymers, which, when optimally synthesized, produce local and giant stiffness changes in a controllable manner. Featuring complex geometries, the generated structures and metamaterials exhibit fundamentally different yet programmable nonlinear force-displacement relations and deformation patterns as temperature varies. The rational design and fabrication establish an objective-oriented synthesis of metamaterials with freely tunable thermally adaptive behaviors. This imbues structures and materials with environment-aware intelligence.

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HEALING PERFORMANCE OF ENCAPSULATED FUNGI-BASED SELF-HEALING CONCRETE

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ABSTRACT

This study aims to investigate the development of highly efficient self-healing concrete using fungi. A filamentous fungus strain, Fusarium oxysporum, was chosen, and the study revealed its capacity to germinate and cultivate mycelium within a concrete environment. The alkaline nature of concrete, however, exhibited a decelerating effect on the growth of Fusarium oxysporum. To address this, an innovative approach was explored to establish efficient self-healing concrete by employing a calcium-alginate-based encapsulation technology. Fungi-containing capsules were incorporated into mortar samples at mass ratios of 2%, 3.5%, and 5% to the cement content. The efficacy of this encapsulated fungi-based technology in healing cracks of various sizes in concrete was assessed. Fourier-transform infrared (FTIR) results demonstrated that cracks narrower than 0.1 mm in control samples experienced autogenous healing, while samples containing fungal capsules exhibited a dual healing process involving both autogenous and fungi-based mechanisms. Notably, medium-sized cracks (ranging from 0.1 mm to 0.4 mm) in mortar samples containing fungal capsules achieved complete healing within a 14-day period. The introduction of varying proportions of fungal capsules into mortar samples yielded an impressive repair rate ranging from 73.4% to 94.3% for cracks wider than 0.4 mm, a challenge for conventional self-healing methods.The augmentation of fungal capsule content led to substantial improvements in healing wider cracks. In samples containing 2%, 3.5%, and 5% capsules, healing rates escalated by 464%, 554%, and 597%, respectively, compared to the modest 15.8% rate in control samples. Additionally, the hydrophobic fungal mycelium covering both crack and mortar surfaces significantly curtailed water infiltration, providing an additional advantage by reducing water infiltration and prolonging the durability of structures.

Resilience of coastal structures, systems, and community subjected to hazards

May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

RISK ASSESSMENT OF SEAWALL OVERTOPPING CONSIDERING UNCERTAINTIES UNDER CLIMATE CHANGE

Xukai Zhang[1] and Arash Noshadravan[1]*

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ABSTRACT

This study aims to enhance the protection of coastal communities by better assessing future uncertainties in predicting the risk of failure in coastal defense structures. Sea Level Rise (SLR) poses significant risks to coastal areas, particularly during hurricanes characterized by strong winds and waves. Seawalls, serving as the primary defense, are designed to safeguard seashore infrastructure. However, climate change impacts necessitate reassessing seawall risks, considering potential changes in coastal forces since their initial design. The potential seawall failure, particularly through wave overtopping, poses a serious threat, potentially causing catastrophic flooding in coastal communities. To better understand and characterize the long-term reliability of coastal defense structures amid future uncertainties from SLR and extreme climatic events, a rigorous time-variant reliability framework is proposed for quantifying the risk of overtopping discharge. The carrying capacity in the limit state function is derived from established standards. The overtopping load is determined through prediction with challenges on numerous uncertainties. The proposed probabilistic framework for assessing the risk of overtopping consists of two key components. Firstly, it considers the probability of overtopping discharge based on a specific SLR at seawalls. Secondly, it examines the probability of a specific SLR at seawalls, taking into account various factors such as offshore and nearshore weather conditions, topology, mean SLR change, and more. The factors influencing SLR are categorized into seashore conditions (mean water level at seawall, local weather conditions) and offshore conditions (surges, topology). Predicting SLR at seawalls involves simulating wave propagation from offshore to nearshore, achieved by capturing the relationship between different sensors in these areas. Offshore sensors play a crucial role in recording swell waves that propagate towards nearshore. Additionally, they capture offshore wind conditions, aiding in mitigating the impact of offshore wind on waves. On the other hand, nearshore sensors focus on collecting local wind data. Combining the effects of local wind and waves from offshore provides a comprehensive understanding of the SLR at seawalls. To validate the prediction model, the study compares the predictions of SLR with data obtained from sensors. Ultimately, given a specific SLR at seawalls, the probability of overtopping is determined based on factors such as seawall geometry, local weather conditions, wave speed, etc. The Galveston Seawall on Texas coast is used as a case study. The proposed model functions as a risk-based predictive tool, playing a crucial role in facilitating informed decision-making processes related to coastal infrastructure management and mitigation strategies.

Advances in computer vision, deep learning and artificial intelligence for structural health monitoring and inspections
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

AI-ENHANCED ESTIMATION OF POST-DISASTER DEBRIS USING AERIAL IMAGERY

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[2]*Texas A&M University*

ABSTRACT

Seeking to enhance the efficiency of post-disaster recovery, this study focuses on utilizing artificial intelligence (AI) and unmanned aerial vehicles (UAVs) for the estimation of debris volume and composition in residential structures. This approach, informed by AI-based damage assessment considering building characteristics, design, and construction methods, aims to address the challenges posed by natural hazards which generate significant debris. These challenges include the expensive and challenging task of debris removal, which forms a considerable part of government budgets for hazard mitigation. Erroneous debris estimation and delayed clean-up operations can endanger public health, obstruct post-disaster search-and-rescue (SAR), and hinder resource distribution efforts by impeding access to affected areas. Traditional methods for disaster debris estimation are often imprecise, with errors as large as 50%. This research, incorporating scaled experiments and analysis of recent hurricane damage footage, indicates that the proposed AI-based approach can be promising in predicting the volume and composition of disaster debris. This finding is expected to provide timely critical insights for emergency response and recovery planning, and for making informed decisions that could reduce the overall debris burden.

Probabilistic assessment, data-driven inference and optimization for decision-making under uncertainty
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

GRAPH NEURAL NETWORKS FOR POWER GRID RISK MANAGEMENT

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ABSTRACT

The increasing adoption of renewable energy resources (RES) in power grids, and additional technologies such as bulk storage, gas turbine and flexible plugin devices brings significant uncertainty to power grid management. Hence it is of great significance to assess the risk associated with a power dispatch decision to promote operators' situational awareness. Quantifying the operational risk under uncertainty requires to solve large number of optimal power flow (OPF) analyses and generator commitment (referred to as security-constrained unit commitment, SCUC) problems to cover a wide range of probabilistic forecasts of load demand and RES power supply. However, it is computationally prohibitive to solve numerous OPF and SCUC problems (both of which are optimization problems) within the decision window using numerical solvers, especially for large power grids. Therefore, it is necessary to develop efficient surrogate models that can solve OPF and SCUC problems quickly and accurately to deal with the frequent variation of grid variables.

In this work, graph neural network (GNN)-based surrogate models are developed to facilitate OPF and SCUC computation. The fundamental idea of GNN is to consider grid variables at each node as a feature vector and recursively update its representation according to neighborhood information. GNN takes the advantage of grid network topology in the calculation process and thus promotes the computational efficiency significantly. A well trained GNN model can provide quick and accurate OPF and SCUC predictions for various load demand and RES supply scenarios, making it a good choice for real-time operational risk assessment.

GNN surrogate models are trained in this work using supervised learning with numerical solutions as ground truth. The surrogates take load demand and RES power supply as inputs and predict multiple outputs including active power (node-level), transmission line flow (edge-level) and load shedding, operating reserve and total cost (system-level). Given the probabilistic forecasts of demand and supply, GNN surrogates can quickly generate numerous Monte Carlo (MC) samples which are then used for risk quantification. Versatile tools are developed to allow model evaluation and network risk assessment, and model generalization capacity is also investigated using statistical metrics. It is shown that the GNN surrogates are sufficiently accurate for predicting the grid state and enable fast as well as accurate operational risk quantification and risk management decision-making. The GNN approach can also be generalized for other infrastructure systems with network structure.

Surrogate modeling for uncertainty quantification, optimization, and statistical inference in engineering applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

LSTM FOR METAMODELING OF HIGH-DIMENSIONAL STOCHASTIC SYSTEMS AND ITS APPLICATION TO ACTIVE LEARNING-BASED RELIABILITY ANALYSIS

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ABSTRACT

Metamodeling techniques have received increasing popularity in recent years since they can replace the original time-consuming physical model and remarkably reduce the computational burden. Commonly used surrogate models such as polynomial chaos expansion and Gaussian process regression are widely used and show their feasibility and superiority in the field of uncertainty propagation. However, they can hardly be applied to the high-dimensional stochastic dynamic systems since a large number of random variables are required to simulate the stochastic excitation. To tackle this issue, a powerful machine learning tool termed the long short-term memory (LSTM) is employed to deal with the stochastic excitations. LSTM can well capture the time-dependent property of the sequency-to-sequency data, which can be employed to predict the structural time history responses and circumvent the high-dimensional random phases for generating the stochastic excitation. Besides, to consider the uncertainties of structures, the structural random variables are embedded into the LSTM network. Moreover, to address the insufficient efficiency of neural network for uncertainty propagation results from the limited observations, the active learning strategy is combined with the LSTM to improve the accuracy of reliability analysis, which makes the active learning available for the high-dimensional stochastic dynamic systems.

Advanced engineering concepts, designs, and technologies for aerospace and extraterrestrial applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

HOT DEFORMATION OF METALLIC HONEYCOMBS: MECHANISMS AND MODELLING

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ABSTRACT

Architected cellular materials exhibit exceptional mechanical properties, such as ultralight, ultrastiff, and even respond to external stimuli through tailoring geometry and topology rather than changing composition. Such materials have the potential to be applied in extraterrestrial construction and expeditionary efforts, which usually require them to perform under high-temperature environments. Despite this, limited research investigated the performance of architected cellular materials under high temperatures. Addressing this gap, our study utilizes recent advances in additive manufacturing to create a series of heat-resistant alloy honeycomb structures using ABD-900AM. This research focuses on the processing, characterization, and analysis of the deformation behavior of these metallic honeycomb structures at both room temperature and 900°C. Through a combination of experiments and simulations, we have gained a comprehensive understanding of the deformation mechanisms and their interaction with damage pathways across various temperatures. Additionally, we explored the effects of oxidation and the intrinsic ductility of the material.

Uncertainty quantification and machine learning for design, optimization, and inference in multiscale systems
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

OPERATORS LEARNING FOR MULTISCALE MODELING: AN EXAMPLE OF ELASTIC-VISCOPLASTIC STRUCTURAL MATERIAL

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ABSTRACT

Multiscale systems, due to its complexity in mechanisms, attract significant attention, such as the work on statistical and model errors [1]. Many machine learning frameworks have been developed to obtain surrogate models to reduce the computational complexity of such multiscale systems. One of the fundamental challenges is the dependence of machine-learned models on the discretization of input data matching that of the training data. In solid mechanics, the mapping from the function space of deformation gradient to the function space of Cauchy stress is an operator which should be discretization-invariant. Here, our principal contribution is that we apply the recurrent neural operator (RNO) framework to learn the solution operator between the homogenized strain and the homogenized stress for a material at microscale. The RNO is an architecture of deep neural networks that can give insight into the physics of the macroscopic problem, such as the number of internal variables [2]. As an example, we consider a two-dimensional truss structure, where each truss is elastic viscoplastic. RNOs are learned from the deformation gradient to the homogenized Cauchy stress of the microscale model. We will talk about the discretization invariant property of the RNOs and the insight obtained from the internal variables theory of the microscale model. Then we apply the RNOs to multiple macroscale problems subject to various boundary conditions. Further improvement of the RNOs for macroscale models and relevant uncertainty will be explored and discussed [3].

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ACOUSTIC EMISSION MONITORING AND DIAGNOSIS OF INTERFACIAL BOND-SLIP DAMAGE OF CFST COLUMNS

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[2]Guangxi University

ABSTRACT

CFST structures are composed of steel tubes filled with concrete, and they have strong load-bearing capacity and excellent seismic performance. The use of CFST structures in large-span arch bridges can effectively reduce the self-weight of the structure and improve the overall stability of the bridge. However, the bonding performance between the steel tube and the core concrete has a significant impact on the overall load-carrying capacity of CFST structures. In order to study the damage law of the interface between concrete and steel tube in CFST columns, we propose a real-time monitoring and evaluation method for interface damage of CFST columns based on acoustic emission technology. Push-out experiments of CFST column interfaces were conducted to collect acoustic emission signals of interface damage. Through the analysis of acoustic emission characteristic parameters, RA-AF correlation analysis, and b-value analysis, the identification of damage stages, analysis of crack propagation, and evaluation of damage severity of the interface bonding failure process can be achieved. Based on acoustic emission hit rate, cumulative ring count, and cumulative energy features, the damage process of CFST column interfaces can be accurately divided into elastic stage, slip expansion stage, and complete slip stage. Through RA-AF correlation analysis, the crack development pattern of CFST column interfaces is revealed. The b-value analysis effectively reflects the severity of damage in CFST interfaces. The research findings above can provide a foundation for the application of acoustic emission technology in practical CFST arch bridge engineering and theoretical support for the full-life safety monitoring and operational maintenance of CFST arch bridges.

Keyword: CFST, Acoustic emission, Interface failure, Push-out test, Damage monitoring

Architected materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

INVESTIGATING BENDING, RADIAL, AXIAL, AND TORSIONAL MECHANICAL BEHAVIOR OF A NOVEL TUBULAR METAMATERIALS

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[1]University of Louisville
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ABSTRACT

Strengthened tubular structures have had a significant impact on various industries. Advancements in aircraft, construction, medical implants, robotics, and renewable energy have improved safety, efficiency, and durability in multiple sectors. This section explores the practical applications of medical health, using Nasal Swabs as an example, under different loading scenarios. Oue designed tubular strecutures provides a promising perspective on enhancing the mechanical performance of tubular structures. To evaluate the mechanical advantages of the bioinspired design approach, we conducted 3-point bending, radial, and axial compression tests on 3D printed tubular lattice structures. The tests showed that the tubular structure displayed improved bending properties and was approximately twice as stiff as traditional tubular designs. Furthermore, the sponge-inspired design exhibits significantly higher strength and toughness compared to traditional designs, with approximate improvements of 3 and 4 times, respectively. Numerical simulations revealed that these enhancements are attributed to the strengthening effect of struts, which distribute stress evenly and allow for bending without excessive stress concentration. The design shows improved resistance to radial and axial loading, with approximately 1.3/3 times greater radial/axial compression stiffness compared to unreinforced designs. These improved mechanical properties of tubular metamaterials make them suitable for a wide range of applications.

DIGITAL TWINNED CYBER-PHYSICAL SYSTEM FOR UNDERSTANDING INFRASTRUCTURE OPERATIONAL STATE

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ABSTRACT

The primary aim of this research is to introduce a digital twin-enabled cyber-physical system designed to comprehend the operational state of infrastructure systems. This system integrates AI-driven simulation and experimentation within a real-time collaborative environment, enhancing the understanding of an infrastructure system's current operational state. This approach proves more adept at sensing, analysis, and diagnosis. Accurately and efficiently assessing infrastructure system operational state, such as determining the safety level of aging bridge components or evaluating the energy dissipation capacity of fuse components within a lateral force resisting system after seismic events, is pivotal for informed decision-making processes. To materialize this digital twin-enabled cyber-physical system, AI-powered simulation models, validated against Finite Element Modeling (FEM), and AI-driven image-based experimental measurement models using Digital Image Correlation (DIC) are leveraged for real-time estimations. This study introduces a Mixed Reality (MR) environment, enabling users to interact by selecting baseline AI simulations (e.g., structural members with idealized boundary conditions) and adjusting model parameters (e.g., boundary conditions, constitutive properties) or identifying uncertain features (e.g., damage locations) based on image-derived observations. Validating the proposed Digital Twin prototype involves employing full-scale beam experiments and simulations to assess real-time accuracy, reliability, and computational expenses. Overall, this research establishes communication protocols between AI-driven simulation and AI-powered experimentation and resolves real-time data processing that allows for user engagement and exploration across visualization platforms. The digital twin-enabled cyber-physical system can be extrapolated to larger-scale infrastructure, enhancing efficient human decision-making, and contributing to the evolution of structural health monitoring.

Recent advances in sensing, SHM, and automated inspections for infrastructure condition assessment: Toward actionable solutions
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

IMAGE-BASED REAL-TIME BEHAVIOR MEASUREMENT OF PHYSICAL INFRASTRUCTURE SYSTEMS DRIVEN BY DEEP LEARNING

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ABSTRACT

This research aims to introduce an AI-enabled real-time measurement protocol for assessing complex behaviors within physical infrastructure systems, employing the Digital Image Correlation (DIC) technique. The efficient and accurate evaluation of the operational state of infrastructure systems, such as determining the safety level of bridges in service or evaluating the energy dissipation capacity of lateral force resisting systems after seismic events, is pivotal for human decision-making processes. While DIC has revolutionized full-field measurements and non-destructive assessments, its data-intensive nature and requirement of complex equation solution have limited real-time applications. This study proposes to employ AI-driven approaches to formulate real-time measurements of physical infrastructure systems and enable user-guided inquiries of behavior during experiments, thus further enhancing analysis and diagnosis capabilities. To realize AI-driven real-time measurements, a deep Convolutional Neural Network (CNN) is developed to learn correlations between sequences of DIC speckle pattern images and their corresponding deformation fields. The proposed CNN will be first developed for 2D speckle patterns and the corresponding in-plane deformation field and then extended to 3D. Utilizing both artificially curated speckle pattern image pairs with pre-defined deformation patterns and real-world speckle datasets taken from past experiments, the CNN model is trained. The CNN model will be tested on experimental data collected from full-scale structural response experiments subjected to diverse loading and boundary constraints, unseen during training. The research herein can be further incorporated into a digital twin-enabled cyber-physical system. The implications extend to larger-scale infrastructure, augmenting human decision-making efficacy, and advancing structural health monitoring practices.

Engineering Mechanics Institute Conference and Probabilistic Mechanics & Reliability Conference (EMI/PMC 2024)

Data-driven methods and research for physical testing in structural engineering
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DATA-DRIVEN PREDICTION MODELS FOR THE BACKBONE CURVE OF COLD-FORMED STEEL FASTENER CONNECTIONS

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ABSTRACT

The main objective of this study is to present the recently assembled cold-formed steel (CFS) fastener connection test database, and to investigate the application of machine learning models on fastener connection backbone prediction. Predicting the behavior and performance of fastener connections, as significant nonlinearity may arise from materials, contact, and connected structural members. Therefore, experimental testing plays a dominant role in studying the behavior of CFS connections, as well as providing valuable data covering strength, drift, and hysteretic behaviors. A large data set for CFS fastener connection load-deformation response was initiated, which currently holds 550 monotonic and cyclic load-deformation response curves from tests on screw-fastened and power-actuated fastened ply-to-ply connections. On top of the design provisions for CFS fastener connections derived from testing data, data-driven predictions, from various machine learning algorithms, may provide reliable, widely applicable, and efficient predictions on the strength or even the full backbone curve of fastener connections. The research herein employs a series of machine learning models including Support vector machines (SVMs), Artificial Neural Network (ANN), Random Forest (RF), and eXtreme Gradient Boosting (XGBoost) are constructed and trained to provide backbone prediction for CFS fastener connections. The performance of various machine learning algorithms is compared and discussed. Features impacting the connection strength mostly are provided by the algorithms and further discussed. This research can make high-quality data-driven models and corresponding CFS connection physical test data easily accessible, and the data-can advance state-of-art CFS connection design and research.

Engineering Mechanics Institute Conference and Probabilistic Mechanics & Reliability Conference (EMI/PMC 2024)

Resilience of coastal structures, systems, and community subjected to hazards
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

ROLE OF INSURANCE CLAIMS DATA FROM HURRICANES IN CATASTROPHE MODELING

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ABSTRACT

Catastrophe models are an integral part of the insurance value chain and help transfer the risk between homeowners, (re)insurers and capital markets. Calibration and validation of models therefore becomes extremely crucial in obtaining reliable and robust risk estimates. Numerous studies exist in the risk and actuarial space that demonstrate various utilities of insurance claims data in the insurance value chain. These include use of claims data to inform underwriting decision, owning the view of insurer’s risk in terms of adjusting, calibrating and validating catastrophe modeling outputs.

This study presents two novel applications of insurance claims data towards building catastrophe models with focus on hurricanes. The first study looks at identifying damage patterns among residential claims specific to hurricanes. Post-hurricane damage surveys have shown that buildings with specific characteristics exhibit different damage patterns. This study analyzes the claims data collected in the aftermath of 2017 Hurricane Irma as a case study. The Density-Based Spatial Clustering of Applications with Noise (DBSCAN) method is used for geospatial data clustering and outlier analysis. With the DBSCAN method, clusters and outliers of damaged versus intact buildings are detected. The clusters help locate strong and weak neighborhoods during the hurricane and analyze the influential factors. Results show that the replacement value of residential homes is an important factor in damage formulation. A clear separation was observed between homes with a replacement value threshold of about100,000 USD, which cannot be clearly detected in the raw data without clustering and outlier analysis.

The second study explores the use of claims data to understand relative vulnerability as a function of wind speed between buildings used for various functional purposes, referred to as occupancy. Vulnerability functions, also referred to as damage functions are frequently used in catastrophe models and help derive estimates of damage ratio (ratio of loss to the replacement value) as a function of intensity. The relativities between occupancy classes are developed using a multi-task learning (MTL) method. The MTL method allows fitting damage function curves for multiple occupancy classes in parallel. It considers the commonality between fitting tasks and improves the generalization of fitted models with less overfitting. Moreover, through implementation using a neural network model, the MTL method provides an approach for synergistically combining the claims data and engineering knowledge in the damage function development.

Modeling and characterization of brittle and quasibrittle fracture
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DYNAMIC RUPTURE MODELING IN A COMPLEX FAULT ZONE WITH DISTRIBUTED AND LOCALIZED DAMAGE

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ABSTRACT

Earthquakes are among the most destructive natural hazards in our planet. They also present a unique opportunity to study dynamic fracture at scale, but their underlying physics remain far from being fully understood. While at some level, earthquakes exemplify quasi-brittle fractures occurring along frictional fault interfaces, these events can also dynamically trigger co-seismic off-fault damage, manifesting as both distributed and localized effects that influence fault zone geometry and rheology. To accurately quantify the impact of dynamic ruptures on the bulk materials within the damage zone, it is essential to employ numerical models capable of capturing the evolving material properties guided by field observations.

Here, we implement a continuum damage breakage (CDB) rheology model in our MOOSE-FARMS dynamic rupture simulator to investigate the interplay between bulk damage and fault motion on the evolution of dynamic rupture, energy partitioning, and ground motion characteristics.

The CDB rheology model combines aspects of a continuum viscoelastic damage framework for brittle solids with a continuum breakage mechanics for granular flow within dynamically generated slip zones. It consists of a scalar damage parameter to account for the density of distributed cracking, along with a breakage parameter to represent grain size distribution of a granular phase. The model can capture both the degradation in the elastic properties and the brittle instabilities which further promote post-peak rheological softening and transition into granular flow. MOOSE-FARMS is an in-house application developed based on MOOSE framework to simulate dynamic rupture using cohesive zone model. It accepts various frictional laws, fault geometries, and bulk rheologies.

We demonstrate several effects of damage and breakage on rupture dynamics in the context of two prototype problems addressed currently in the 2D plane strain setting: (1) a single planar fault and (2) a fracture network. We quantify the spatial-temporal reduction in wave speeds associated with dynamic ruptures in each of these cases and track the evolution of the original fault zone geometry. The results highlight the growth and coalescence of localization bands as well as competition between localized slip on the pre-existing faults vs. inelastic deformation in the bulk. We analyze difference between off-fault dissipation through damage-breakage vs. plasticity and show that damage-induced softening increases the slip and slip rate, suggesting enhanced energy radiation and reduced energy dissipation. We discuss the implications of these results on our understanding of earthquake source and fault physics as well as near-fault seismic hazard.

Design and additive manufacturing of engineering structures and materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

AUTOMATED DESIGN-ANALYSIS-OPTIMIZATION WORKFLOW FOR AEROSPACE STRUCTURES USING ISOGEOMETRIC KIRCHHOFF–LOVE SHELLS

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ABSTRACT

Shell structures, known for their exceptional stiffness and strength-to-self-weight ratios, play an important role in aircraft design. The geometric properties of these structures have significant impacts on their performance, making shape optimization essential for achieving superior designs. In industrial standards, computer-aided design (CAD) models of aerospace structures are represented by a collection of Non-uniform rational B-spline (NURBS) surfaces. In this work, a FEniCS-based Python framework using isogeometric Kirchhoff–Love shell model [1] is presented to enable direct structural analysis for CAD models, entirely bypassing the process of finite element (FE) mesh generation. To ensure displacement and rotational continuity at NURBS surface intersections, a penalty-based coupling formulation is implemented [2]. The unified description between CAD and analysis models in isogeometric analysis (IGA) provides a unique advantage in shape optimization, where the control points of the CAD model served as design variables are updated directly during optimization. Therefore, the same NURBS basis functions can be employed to represent the updated geometry for analysis in subsequent optimization iterations, making the associated CAD model directly applicable in manufacturing. In the optimization process, the free-form deformation (FFD) technique is employed to perform shape optimization of aerospace structures while preserving connectivity at surface intersections [3]. The CAD geometry is embedded in a trivariate B-spline block, whose shape is updated through control point adjustments of the B-spline block. Furthermore, a novel scheme is proposed for shape optimization with differentiable surface intersections, allowing for the movement of shell intersection locations without compromising the mesh quality of NURBS surfaces. We apply this methodology to optimize the layout of internal stiffeners in an aircraft wing to demonstrate its benefits in real-world aerospace design scenarios.

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ENHANCING THE EFFICIENCY OF EARTHQUAKE RUPTURE FORECASTING MODELS WITH ADAPTIVE IMPORTANCE SAMPLING IN REGIONAL SEISMIC RISK ASSESSMENT

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ABSTRACT

In regional probabilistic seismic risk analysis (PSRA), the uncertainty of earthquake rupture (e.g., magnitude, epicenter, etc.) and aleatory ground motion uncertainty must be considered. Such uncertainty is conventionally propagated to civil infrastructure responses using a two-step Monte Carlo (MC) method. In the first step, the uncertainty in the earthquake rupture scenario is considered, and a number of earthquake scenario samples are generated. In the second step, a mean field of ground motion intensity measures is estimated for each scenario using ground motion prediction equations (GMPEs), and inter-event/intra-event residual samples are added to the mean field to create a number of ground motion field (GMF) samples. The GMF samples are then used as the input to determine civil infrastructure performance. The first MC step is usually called earthquake rupture forecast (ERF) and requires expertise in seismology. As a result, earthquake engineers usually take the scenario samples created by developed ERF models and create GMF samples for the sample scenarios.

Because a number of GMFs are sampled for each ERF scenario, the number of GMF samples can be huge (almost 700,000 in the PSRA of a region in New Zealand [1]). The importance sampling (IS) method has been proposed to apply in both MC steps to reduce the number of GMF samples [2]. However, the IS method is difficult for practitioners to apply because it is not implemented in the preestablished ERF models. As a result, this research proposes a workflow to reconstruct a set of IS samples from the uniform MC samples produced by ERF models. A sampling-based adaptive algorithm is introduced to estimate the optimal proposal IS densities across conflicting outputs, and a PCA-based formulation is applied to handle the high-dimensionality of outputs. The algorithms will be demonstrated with a PSRA of a transportation system. The proposed method is expected to produce smaller estimation variances than existing IS algorithms because an optimal proposal density is selected. The proposed method is also unbiased, which is a property that the optimization-based down-sampling algorithms don't preserve and is easier to apply by earthquake engineers.

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Objective resilience: Computational advancements for performance-based engineering and resilience assessment of communities
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

TOWARDS A COMPUTATIONAL PLATFORM FOR INTEGRATED REGIONAL RESILIENCE ASSESSMENT OF INTERDEPENDENT SYSTEMS

Nikola Blagojevic[1], Jinyan Zhao[2], Sina Naeimi Dafchahi[2], Adam Zsarnoczay[3], Frank McKenna[2], Matthew DeJong[2] and Bozidar Stojadinovic[1]*

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ABSTRACT

Compared to the existing regional risk assessment tools, regional resilience assessment tools need to consider the post-disaster recovery of the built environment, thus estimating its ability to bounce back following a disaster. Furthermore, the built environment needs to be viewed as a system-of-interdependent-systems, instead of an aggregate of individual assets. To that end, the SimCenter's R2D Tool is integrated with the pyrecodes open-source software for regional resilience assessment to extend the R2D Tool's risk-assessment capabilities beyond direct losses by simulating the post-disaster regional recovery of interdependent systems, thus capturing indirect losses, such as system downtime, population displacement and business interruption. Recovery simulation of an individual system in pyrecodes requires two modeling elements: one to simulate the recovery of systems' components and the second one to simulate the flow of resources among components. Recovery is simulated as a time-stepping loop where at each time step the functionality of components is updated, conditioned on the available recovery resources and the progress in component's impeding factors and repair. The simulated flow of resources among components captures interdependencies: at each time step of the recovery simulation, each component's ability to supply resources to other components is conditioned on the component's resource demand fulfilment, assessed using resource flow models. The recovery and resource flow simulation of individual systems can be performed using the algorithms in pyrecodes or using third-party simulators which connect to pyrecodes using standardized application programming interfaces (APIs). The integrated regional resilience assessment of interdependent systems is demonstrated by assessing seismic resilience of the city of Alameda, CA, considering three interdependent systems: the building stock, the transportation network and the water supply network. Two infrastructure systems simulators are integrated within the R2D Tool and pyrecodes workflow using different integration modalities. The traffic flow is simulated using the spatial queue model and the recovery of the transportation system is simulated using pyrecodes' built-in algorithm, while both the recovery and resource flow of the water supply system are simulated using the REWET software. The recovery of the building stock and the flow of resources provided by the building stock are simulated using pyrecodes' algorithms.

On the mechanics of road and paving materials in the cold, Nordic, and Arctic Regions
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

RESEARCH ON THE DEFORMATION AND DAMAGE PROCESS OF CRUSHED-ROCK HIGHWAY EMBANKMENT IN PERMAFROST AREAS

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ABSTRACT

Most current research on crushed-rock interlayers for highway embankments in permafrost regions primarily focuses on thermal properties, with limited exploration of their mechanical deformation characteristics. To address this gap, this study investigates the deformation and failure processes of crushed-rock interlayers under long-term settlement deformation of permafrost foundations. The study employs a coupled Finite Element Model (FEM) and Discrete Element Model (DEM) to comprehensively consider the discrete characteristics of the crushed-rock interlayer.

In contrast to previous DEM-FEM coupling methods, this study introduces a static FEM coupled with an explicit DEM process to simulate the long-term settlement deformation of crushed-rock interlayer highway embankments and permafrost foundations over a 20-year period. The coupling algorithm involves calculating temperature fields and long-term freezing and thawing foundation deformation in the FEM model, with the thermal control equations developed by our research group [1] and the E-P constitutive model developed by Zhang et al. [2]. Deformation calculations for the crushed-rock interlayer are carried out in the DEM model. The interaction between FEM and DEM is facilitated through force and coordinate data transfer using Python-coded scripts and a Fortran-coded DLOAD subroutine. Notably, relative velocities at the contact points between DEM and FEM are ignored due to the slow speed of the long-term deformation.

The results indicate that for the granite blocks employed in the Gonghe-Yushu expressway, the blocks are seldom broken. Instead, the deformation of the crushed-rock interlayer primarily results from the relative movement and rearrangement of the blocks. It is recommended to adopt a large-porosity randomly piled crushed-rock interlayer composed of blocks with sharp corners. When the size of block varies from 20cm to 40cm, the block size has no obvious effect on the deformation of crushed-rock interlayer, therefore the block size could be determined only by the cooling effect. At the meantime, the structure layer above the crushed-rock interlayer should also be rigid enough to ensure a smaller uneven settlement value for the superstructure.

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LUNAR HABITAT ARCH-SHIELD OPTIMIZATION FOR COMPLEX LOAD COMBINATIONS WITH ML

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ABSTRACT

The scientific curiosity and passion for space exploration, driven by technological advancements and increased computational power, have been rekindled at academic institutions and private companies. Constructing a permanent human habitat on the Moon is generally regarded as the next challenge and an outpost of further exploration missions to other celestial bodies. The concept of using inflatable structures with a regolith 3D-printed shield is getting momentum in tandem with advancements in additive manufacturing technologies. This paper focuses on the search for an optimal arch shape of such regolith-based structures by addressing the challenges caused by multiple load combinations, including gravitational, thermal, and seismic loads. This process can be viewed as an optimization of a high-dimensional data space, and autoencoders, a type of unsupervised machine learning, can be leveraged to explore it. These models compress data into a reduced latent space and reconstruct the original data from these reduced dimensions, which means once optimal latent space variables are identified, the models can reconstruct the desired output shapes. To ensure the reliability of the model, the generation of training data sets and the choice of optimization methods are crucial. For data set construction, a random sampling method is employed to maximize coverage, and then corresponding contoured datasets reflecting maxima of stress and displacement responses are generated by means of algorithms running Abaqus models. For the optimizing procedure, Bayesian Optimization is applied to conduct multi-objective optimization. The optimal shapes obtained in this study are compared with previous proposals and the differences are highlighted. This study provides a valuable reference for future regolith-based shape design.

Intelligent techniques and deep learning for bridge health monitoring
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

REINFORCEMENT LEARNING-POWERED MODEL-FREE FRAMEWORK FOR UAS-BASED BRIDGE COLUMN INSPECTION MISSION PLANNING

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ABSTRACT

The application of Unmanned Aerial Systems (UAS) in bridge inspection has been extensively discussed. Various studies have investigated mission planning methods for efficient and reliable bridge inspection, while most of them rely on a CAD model or preliminary scanning data as inputs, which are not often available in practical scenarios. This work aims to achieve higher-level automated inspection by introducing a reinforcement learning based, model-free mission planning framework specifically for inspecting bridge columns, eliminating the need for input data. A parametric environment generator was employed to create diverse bridge column plans, which is the basis for training the agent. As the core of this mission planning approach, a deep neural network served as the agent. It iteratively processed the environment map and position inputs and generated decisions regarding movement or scanning to formulate an optimal inspection plan. During agent training, the efficiency of the mission plan was evaluated as a reward, constrained by inspection quality. The techniques for obtaining observations were also discussed for future real-world application. The proposed framework demonstrated the feasibility of utilizing reinforcement learning in on-line mission planning for bridge column inspection, significantly enhancing the automation and performance of bridge inspection procedures.

Architected materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MULTIPHYSICS TOPOLOGY OPTIMIZATION OF ARCHITECTED MAGNETIC SOFT MATERIALS WITH CONTINUOUS MAGNETIZATION ORIENTATIONS

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ABSTRACT

In recent years, magnetic-responsive soft architected materials have garnered attention for their wireless and rapid actuation capabilities under magnetic fields, enabling versatile applications in robotics, biomedicine, and vibration mitigation. This study specifically focuses on hard-magnetic soft materials made by embedding high-coercivity magnetic particles, such as neodymium–iron–boron alloy, within a soft matrix, providing remarkable programmability and various functionalities. From a design perspective, many current designs for the architected magnetic material exhibit discrete magnetization orientations, potentially limiting actuation performance and posing fabrication challenges at magnetization transition points. This work introduces a novel multiphysics topology optimization framework that simultaneously optimizes geometry and ensures continuous remnant magnetization distributions in the architected magnetic material. The optimized continuous magnetization offers several demonstrated advantages: 1) Enhanced actuation performance through an expanded design space with arbitrary magnetization orientations; 2) Mitigation of undesirable sharp changes in magnetization, reducing repelling forces and improving fabricatability; 3) Feasibility of fabricating designs with continuous magnetization using the recently developed magnetic direct-ink-writing technique. Our developed design approach has successfully achieved programmable shape transformations, multi-functional actuators, and magnetic metamaterial with tunable lateral deformation. This innovative approach explicitly explores the potential of architected materials in the context of hard-magnetic soft materials, emphasizing improved enhanced performance and the alleviation of abrupt changes in magnetization orientation.

Topology optimization: From algorithmic developments to applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

TOPOLOGY OPTIMIZATION OF STRUCTURES WITH NONLINEAR SUPPLEMENTAL DAMPING

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ABSTRACT

Extensive research has been done on structural optimization and optimal placement and designs of dampers separately, but there is limited research about simultaneous optimization of structural and damper designs with nonlinearity. Structures in seismic prone regions are often designed with respect to their element's inelastic behaviors such as the use of nonlinear dampers to reduce the structural response, showing the need to consider nonlinearity in the design process. The purpose of this study is to propose a method to perform simultaneous optimization of topology with supplemental damping devices modeled as nonlinear viscous dampers. One observation is that use of nonlinear dampers has impact in the optimal topology as compared with linear dampers. Nonlinear dampers also tend to decrease the optimal drifts and velocities of the system, meanwhile also increase the amount of energy dissipated by damping in the system as compared with linear dampers. In conclusion, optimization of structures considering nonlinear dampers is more effective in seismic damage mitigations and should be included to ensure an optimal design.

Uncertainty quantification and machine learning for design, optimization, and inference in multiscale systems
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

THE PHYSICS-INFORMED COMPOSITIONAL OPERATOR NETWORK

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ABSTRACT

We focus on solving partial differential equations (PDEs) with variable parameters. To this end, neural operators as an effective machine learning method are trained as mapping from these parameters to their corresponding solutions. A significant challenge in training neural operators is the requirement for large datasets of paired input-output examples, which are often expensive and time-consuming to produce. As a solution, neural operators trained through physics-informed methods have gained attention. However, existing physics-informed neural operators struggle with issues such as accommodating irregular domain shapes or generalizing across different dimensions of parameter observations. We propose a novel model architecture that successfully overcomes these hurdles. It is designed to generalize across diverse parameter observation dimensions within irregularly shaped domains. Moreover, this innovative architecture is compatible with physics-informed training, thereby bypassing the need for finite-element methods in creating training data. Our results show that this novel model not only matches but potentially surpasses the performance of traditional data-driven neural operators.

INCORPORATING PCM-ENABLED THERMAL ENERGY STORAGE INTO 3D PRINTABLE CEMENTITIOUS COMPOSITES FOR BUILDING ENERGY SAVING

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ABSTRACT

This resarch delineates the feasibility of incorporating microencapsulated phase change materials (mPCM) into 3D printable cementitious composite materials. A comprehensive experimental program was carried out to evaluate the impacts of mPCM on the printability, microstructures, mechanical and thermal properties of cementitious 3D printing ‘inks’. Results showed that the mPCM affected the printability of the cementitious ink material based on its physical properties (e.g., particle size) and volume loading – at lower volume loadings, mPCM increased the flowability of the cementitious ink material while leading to increased compressive strength and thermal conductivity for the hardened printed material. However, further increase in mPCM dosage led to a decrease in printability and, therefore, decrease in compressive strength and thermal conductivity as compared to the reference mixture. The results also showed that the inclusion of mPCM influence the printing parameters. In general, the inclusion of higher volume contents of mPCM necessitates a higher extrusion rate to achieve a desirable extrudability. Lastly, a thermal network model was formulated for 3D printed mPCM charged building components (e.g., wall). The study shows that microencapsulated PCM materials have good potential to be used in 3D printable cementitious mixtures for improving the thermal and energy performance of 3D printed buildings.

On the mechanics of road and paving materials in the cold, Nordic, and Arctic Regions
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

COAL-DERIVED CONDUCTIVE PAVEMENT FOR WINTER DE-ICING - PROTOTYPE, MODELING, AND SIMULATION

Hongyu Zhou[1], Yawen He[1], Yucen Li[1], Yanhai Wang[1] and Baoshan Huang[1]*

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ABSTRACT

Traditional de-icing methods and heating systems for pavements show limitations in high installation and maintenance costs, traffic delays, excessive weariness, and negative environmental and public safety impacts. In this research, a novel low-cost coal-char bearing multifunctional pavement material was developed and demonstrated for smart self-heating pavements. An innovative pathway to designing and constructing a self-sensing and self-heating pavement system was proposed by incorporating this byproduct of coal pyrolysis as a de-icing system heating layer into the pavement structure. This coal-derived carbon exhibits highly tailorable electrical conductivity, superior cost-efficiency, and wider compatibility for aggregate alternatives as compared to other conductive pavement additives. The coal-char charged asphalt mixture for the self-heating pavement was designed and prototyped. The mechanical, electrical, and thermophysical properties of coal-char bearing pavement materials were characterized through multiscale material tests. A laboratory prototype was produced, and bench-scale slab heating and de-icing experiments were conducted. The test results indicate that the embedded electrically conductive layer made from coal-char asphalt can serve as an effective heating system for de-icing. Additionally, a simulation case study was performed using a thermal network model with experimental calibration to quantify the thermal performance and energy consumption of the de-icing system. A rule-based control strategy is designed for the de-icing system based on heating demands.

Advanced engineering concepts, designs, and technologies for aerospace and extraterrestrial applications
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DETECTION, EFFECTS, AND RETROFITTING OF PRINTING DEFECTS OF 3D PRINTED CONCRETE STRUCTURES

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ABSTRACT

Understanding the effects printing defects have on the mechanical performance of concrete 3D printed structures and developing facile methods for identifying defects and retrofitting structural members is necessary for infrastructure development on the lunar surface and beyond. In this study, various defect sizes, quantifies, and orientations were artificially introduced by placing spherical expanded polystyrene (EPS) foam beads of a known diameter into 3D printed concrete specimens. The effect that the introduced voids had on the mechanical performance was then evaluated by testing cube specimens cut from the printed elements and tested under compression. Methods for identifying both external printing defects on the face of printed elements and internal defects located within printed elements were developed based on computer vision and ultrasonic testing techniques. Next, materials and methods to retrofit the defected specimens were developed. The mechanical properties were characterized to guide the selection of the most effective retrofitting materials. Two materials with the highest capacities in the mechanical properties characterizations were selected. Furthermore, methods for retrofitting printed elements using the materials selected in the previous stage of the project were developed alongside defect detection methods. These methods were then deployed in tandem to retrofit the defected specimens.

Advances in geomechanics and geophysics for modern sub-surface technology and natural hazard
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

FINITE ELEMENT MODELING OF CREEP-INDUCED SUBSIDENCE ALONG COASTAL LOUISIANA WITH GPS MEASUREMENTS

George Z. Voyiadjis[1], Yaneng Zhou[1] and Ahmed Abdalla[1]*

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ABSTRACT

The subsidence rates are generally between 2-7 mm/yr during the last one or two decades based on GPS measurements at continuously operating reference stations along coastal Louisiana. The creep mechanism in Holocene sediments is adopted to quantitatively interpret the observed land subsidence along coastal Louisiana. An extended elasto-viscoplastic model is developed to better consider the viscoplastic deformation for overconsolidated soils with small strain rates. The implemented constitutive model is calibrated and validated in ABAQUS based on both creep and constant rate of strain laboratory experiments for Batiscan clays. Finite element models are then constructed to analyze the creep-induced subsidence for Holocene sediments at several stations along coastal Louisiana. The finite element models are calibrated with GPS-derived subsidence by using the extended elasto-viscoplastic model with typical material parameters for lightly overconsolidated soils. The modeled subsidence decreases significantly with increasing both the initial overconsolidation ratio and the strain-rate exponent, and the subsidence rate decreases with time. Creep-induced subsidence is predicted for several stations based on the calibrated finite element models, and the subsidence is around 30.4 cm in 50 years during 2005-2055 at station GRIS in Grand Isle.

Computational geomechanics
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MULTISCALE MODELLING FRAMEWORK FOR THE MECHANICAL PROPERTIES OF ILLITE

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ABSTRACT

Clay is one the most important materials in earth's crust and has wide applications in geotechnical, environmental, and biomedical engineering. It has complex mechanical properties due to its particulate nature and complex physico-chemical interactions between primary particles. In this presentation, a multiscale framework will be presented, linking the mechanical properties of illite from atomistic up to macroscopic scales. Illite is a typical type of clay with flexible plate-like particles. The framework includes the study of inter-particle interaction at atomistic scale through free energy perturbation calculations with molecular dynamics simulations, from which the potential of mean force will be used to calibrate the coarse-grained force field to be used in meso-scale simulations. The modes of deformation and mechanical response of the mesoscopic systems are incorporated into a thermodynamically consistent constitutive model describing the small-strain elastic stiffness of illite clay at macroscopic level. The simulation results are compared with experimental results on the same material. The framework can provide good guidance on similar multiscale study on physico-chemical properties of clay to facilitate efficient material modification targeting for a greener civil engineering construction practice and has potential application in the investigation of other geomaterials.

Intelligent techniques and deep learning for bridge health monitoring
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

BAYESIAN TWO-STAGE STRUCTURAL IDENTIFICATION WITH EQUIVALENT FORMULATION AND EM ALGORITHM

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ABSTRACT

The use of structural models to simulate and predict structural performance has a longstanding history in engineering. When a model is established, the alignment of model prediction with observed data often relies on parameter selection that reflects model error. An efficient alternative to manual adjustment is Bayesian two-stage structural identification. In this approach, modal properties are first extracted from measured vibration data in Stage I, and then used for determining structural parameters in Stage II. With sufficient data for a globally identifiable problem, the computation often reduces to optimizing a ‘measure-of-fit’ function to yield the ‘most probable value’ (MPV) of parameters, and determining the Hessian to quantify identification uncertainty. Model error is inevitable as no model is perfect. The complexity of addressing it in the identification process calls for a proper computational strategy. In this spirit, assuming Gaussian model error, this work introduces a hypothetical yet mathematically equivalent formulation for the two-stage problem. The proposed formulation facilitates the development of effective algorithms for MPV using Expectation-Maximization techniques. By hypothetically treating the MPV of modal properties in Stage I as ‘data’ and considering model error as latent variables, the Q-function in the M-step can be expressed as a sum of two terms. These two terms can be optimized separately with respect to the structural parameters and model error parameters. The optimization of structural parameters reduces to a Stage II problem without model error, allowing the application of existing algorithms. By considering model error, the resulting posterior covariance matrix is found to give a more realistic quantification of identification uncertainty. The proposed method is investigated with synthetic data and lab data to assess the impact of model errors associated with sensor misalignment and model simplification, as well as the effects of the number of modes and measured degrees of freedom. It is also investigated with field data for reality tests.

Intelligent techniques and deep learning for bridge health monitoring
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A FAST NEWTON ALGORITHM FOR BAYESIAN MODAL IDENTIFICATION IN MULTIPLE-SETUP AMBIENT VIBRATION TEST

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ABSTRACT

Multiple-Setup ambient vibration test (AVT) is regularly adopted when the target is to obtain fine mode shapes with limited number of sensors. The accumulated data size (hours of dynamic responses) and the augmented modal parameters (easily reach hundreds) challenge the performance of modal identification algorithms for their speed and accuracy. A fast Newton algorithm is proposed in this paper to obtain a Laplace approximation of the posterior distribution of modal parameters following the formulation in Bayesian FFT method. The calculation of the Jacobian and Hessian in the Newton algorithm is based on a recently developed expectation-maximization (EM) algorithm, which builds the relation between the conventional likelihood function and the complete-data likelihood function. Since the function form of the complete-data likelihood function is much simpler than that of likelihood function, the Jacobian and Hessian can be obtained in semi-analytical forms using the calculus of complex matrix. The implementation details are presented, e.g., how to accommodate various constraints and how to ensure the positive semi-definiteness of the Hessian. The efficacy of this method is demonstrated using synthetic data from a shear frame model, followed by applications to various field test data from different structures. Results reveal that the proposed method surpasses existing algorithms by at least an order of magnitude in speed while achieves better accuracy. The proposed algorithm offers intuitive derivation, streamlined programming implementation, and eliminates the need for separate posterior covariance calculation, underscoring its practical advantages in multiple-setup AVT.

Origami/kirigami inspired structures and metamaterials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

DESIGN CONSIDERATIONS FOR THICK ORIGAMI WITH APPLICATION IN ADAPTABLE INFRASTRUCTURE

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ABSTRACT

This work introduces a modular thick origami system for deployable large-scale structures with broad applications in rapid construction, disaster mitigation, adaptive building systems, and reusable infrastructure. More specifically, this talk will focus on kinematics and design considerations behind this proposed thick origami system. In this talk, we will first demonstrate the capability of our modular and uniformly thick origami (MUTO) system, showing that a MUTO package can sequentially reconfigure between densely packaging states, load carrying bridge states, column states, and bus stop states. The high-level adaptability of MUTO system is superior to state-of-the-practice and state-of-the-art deployable structure systems for buildings and infrastructure. After the demonstration of the superior adaptability, we will dive deep into kinematics and design considerations for these adaptable thick origami. We will derive thickness equations for developability and flat-foldability of origami vertices, and demonstrate how we can use them to identify potential origami designs. With these two equations, we investigated common thick origami vertices with four creases to ten creases, identifying potential candidates that can produce uniformly thick vertices. From the analyses, we can identify new degree-6 and degree-10 vertex that are not widely studied by the community. These new vertices could be integrated into new tessellations and patterns for future research. We believe the proposed equations provide new methods to design thick origami systems for applications beyond adaptable civil structures, such as deployable aerospace systems, biomedical devices, reconfigurable metamaterials, and many others.

Reference:
Yi Zhu, Evugeni T. Filipov, 2023, Modular and Uniformly Thick Origami for Large-Scale, Adaptable, and Load-Carrying Structures, (Under Review) (http://arxiv.org/abs/2310.03155)

Engineering Mechanics Institute Conference and Probabilistic Mechanics & Reliability Conference (EMI/PMC 2024)

Natural hazard assessment with monitoring, modeling, and uncertainty quantification
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

UNCERTAINTY QUANTIFICATION OF NEGATIVE SAMPLES AND MODEL STRUCTURES IN LANDSLIDE SUSCEPTIBILITY CHARACTERIZATION BASED ON BAYESIAN NETWORK MODELS

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ABSTRACT

Landslide susceptibility mapping (LSM) characterizes the landslide potential which is essential for assessing landslide risk and developing mitigation strategies. Despite the significant progress in LSM research over the past two decades, several long-standing issues, such as uncertainties related to training samples and model selections, remain inadequately addressed in the literature. In this study, we employed a physically based susceptibility model, PISA-m, to generate four different non-landslide data scenarios and combine them with mapped landslides from Magoffin County, Kentucky, for model training. We utilized two Bayesian Network model structures, Naïve Bayes (NB) and Tree-Augmented Naïve Bayes (TAN), to produce LSMs based on regional geomorphic conditions. After internal validation, we evaluated the robustness and reliability of the models using an independent landslide inventory from Owsley County, Kentucky. The results revealed considerable differences between the most effective model in internal validation, which used non-landslide samples extracted exclusively from low susceptibility areas predicted by PISA-m, and their unsatisfactory performance in external validation, highlighting the potential overfitting problem which is largely overlooked by previous studies. Additionally, our findings also indicate that TAN models consistently outperformed NB models when training datasets were the same, due to the ability to account for variable dependencies by the former.

Discrete models for the simulation of infrastructure materials
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

AN ENERGY REGULARIZATION SCHEME FOR THE MULTISCALE LATTICE DISCRETE PARTICLE MODEL

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ABSTRACT

Failure in quasi-brittle materials exhibits several multi-scale characteristics, such as meso-structural heterogeneities, crack coalescence, and damage localization. As a result of this, models that can provide a direct description of the random microstructure of these materials are of great practical and scientific relevance. However, the computational cost associated with such approaches is often prohibitive when simulating full-scale structural systems. For this reason, several multiscale approaches have been proposed in literature to represent the material at the mesoscopic level on a Representative Volume Element (RVE), and bridge such information to the macroscopic level by means of mathematical homogenization. In this manuscript, a modification of the Multiscale Lattice Discrete Particle Model (LDPM) model is proposed to address well-known issues associated with linking the macroscopic mesh configuration and the corresponding RVEs. The novel paradigm is based on an extension of the crack-band model that takes into account the element characteristic lengths of both the macroscopic mesh and the RVE, allowing for the formal quantification of the material properties to be assigned to the mesoscale LDPM simulations, with the ultimate goal of mitigating mesh dependence in the simulations. The feasibility and effectiveness of the proposed regularization scheme are verified by analyzing the response of plain concrete members with various mesh configurations (at both scales) under tensile and 3-point bending conditions and further validated by full-scale experimental data on different reinforced concrete structures.

Structural identification and damage detection
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

IMPURITY GAS MONITORING FOR SPENT NUCLEAR FUEL CANISTERS USING A VARIATIONAL AUTOENCODER (VAE)

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ABSTRACT

The spent nuclear fuel (SNF) canisters are stainless-steel containers that are used to store and/or transport SNF. To provide an inert environment, canisters are backfilled with helium after vacuum drying. However, the gas composition may change during a canister's interim storage period signifying degradation of the system integrity. For example, the fission gases may be released into the canister if the cladding of the fuel rods is breached. Additional impurities such as air and water vapor may also be simultaneously present due to insufficient vacuum drying. A determination of these gas impurities may be useful to identify potential deterioration of canisters. Therefore, monitoring the impurity gas is critical for the safety evaluation of SNF canisters. This study presents a variational autoencoder (VAE) method for detecting impurity gases in SNF canisters. Different impurity gases, argon and air, were backfilled to a sealed canister mock-up with helium. Ultrasonic transducers were mounted on the outside of the canister to probe the internal gas profile. The VAE was trained on the ultrasonic responses collected with pure helium (i.e., the healthy canister), and applied directly to the responses with impurity gases (i.e., the abnormal canister). Research results show that the VAE learns to reconstruct the pure helium signal well with small reconstruction errors. However, the VAE exhibits larger errors when it comes to reconstructing the impurity gas signal. This contrast highlights the capability of VAE to effectively differentiate the pure helium and impurity gases by producing different magnitudes of reconstruction errors. The latent space forms separable clusters for healthy and abnormal canisters. The clusters with higher impurity concentrations deviates further from the pure helium cluster. In addition, the trained decoder can generate high-fidelity pure helium signal by sampling from the standard Gaussian distribution and thus serves as a digital twin of the healthy canister. This combined experimental-computational non-destructive testing approach has potential applications in the safety evaluation of SNF canisters and radioactive waste management efforts.

Plan the future: Innovations in advanced cementitious materials and sustainability
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

MICROMECHANICAL MODEL FOR STRESS-STRAIN HYSTERESIS OF POROUS ROCKS UNDER HYDROSTATIC LOADING

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[1]Imperial College

ABSTRACT

In 1965, Walsh [1] developed a model to explain stress-strain hysteresis in rocks under uniaxial loading, based on the mechanism of frictional sliding along the faces of microcracks. David et al. [2] extended that model by accounting for the closure of initially open cracks, and by extending the quantitative analysis to the full unloading portion of the stress-strain curve. The resulting model was able to fit the full loading-unloading stress-strain curve of several sedimentary and crystalline rocks, using a small number of parameters that each have a clear physical interpretation: uncracked rock modulus, crack density, initial aspect ratio, friction coefficient. Since these models ignore stress-field interactions between nearby cracks, they would predict no hysteresis under hydrostatic loading, since under macroscopic hydrostatic loading, the face of each crack would be subjected to normal traction without a shear component, and therefore would not be liable to slide. However, it is observed experimentally that a small amount of hysteresis does indeed occur during hydrostatic loading.

To extend this type of model to the hydrostatic regime, we assume that the rock contains spherical pores, with small microcracks dispersed throughout the rock "matrix" outside of the pores. In this way, a local deviatoric stress develops, despite the remote loading being hydrostatic. By use of Hashin's spherical assemblage concept, we are able to analyze the behavior of a "unit cell" composed of a single pore surrounded by a cracked matrix. The mechanical behavior of the cracked shell is analyzed using the classical non-interactive scheme of Kachanov. The pore-fluid pressure is assumed uniform through the assemblage, in both the drained and undrained regimes. Analytical expressions for the bulk modulus at critical stages, including crack closure, and maximum forward- and reverse-crack-slipping, are presented. Several sets of experimental data from hydrostatic compression tests on dry sandstones and carbonates, taken from the recent literature, are used to validate the model, showing excellent agreement [3].

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Engineering Mechanics Institute Conference and Probabilistic Mechanics & Reliability Conference (EMI/PMC 2024)

Natural hazard assessment with monitoring, modeling, and uncertainty quantification
May 28-31, 2024, Palmer House Hotel, Chicago, IL, United States

LANDSLIDE DISASTER EMERGENCY RESCUE BASED ON KNOWLEDGE GRAPH RESEARCH ON INTELLIGENT DECISION MAKING

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ABSTRACT

landslide disaster emergency decision-making can effectively reduce the subsequent disaster losses. However, grassroots governments or organizations primarily rely on response plans to carry out rescue operations, and are unable to swiftly make decisions based on a multitude of factors including geological strata properties, hydrological conditions, weather patterns, population distribution in affected areas, among others.The knowledge graph technology can effectively integrate multi-source data information of landslide disasters, and establish disasters entities and relations between entities. The landslide disaster knowledge graph collects data sources such as landslide data, standards and norms, and disaster investigation reports, and builds a NLP entity recognition training corpus in the field of landslide disaster emergency rescue. Through AI models such as BERT, CasRel, and ChatGLM, embedding representation of entities and their relationships such as disaster victims, emergency rescue, and affected areas are established in the high-dimensional semantic space of landslide disasters. The embedding representation made it possible a large number of landslide disaster text reports can be calculated.The landslide disaster knowledge graph reconstructs more than 2000 entities and complex relationships in the form of graph structures, and integrates knowledge such as landslide mechanisms, engineering prevention and control technologies, and emergency processes. The emergency rescue requirements such as disaster assessment and rescue are extracted from the landslide disaster knowledge graph to form a standard SWRL rule library, which provides auxiliary decision-making knowledge support for landslide disaster emergency rescue.