Università degli Studi di Napoli Federico II

DiSt
Department of Structures for Engineering and Architecture

DiSt 2023-2027 Dipartimento di Eccellenza MUR

EMI International Conference 2026

Napoli (Italy), 2-4 September

Congress Centre | University of Napoli Federico II

Via Partenope, 36

Fundamentals in Action: Advancing Engineering Mechanics for the Future

CONFERENCE CO-CHAIRS

Luigi Di Sarno, Napoli, Italy

Paolo Gardoni, Champaign, USA

Andrea Prota, Napoli, Italy

PROGRAM

Welcome Message from the EMI President

Michele (Mike) Barbato
Ph.D., P.E., F.ASCE, F.SEI, F.EMI
University of California, Davis
President, Engineering Mechanics Institute

Dear members of EMI and the broader Engineering Mechanics community,

On behalf of the Engineering Mechanics Institute Board of Governors and the conference organizing committee, it is my great pleasure to welcome you to Naples, Italy, and to the Engineering Mechanics Institute 2026-International Conference (EMI2026-IC). This year's conference, themed "Fundamentals in Action: Advancing Engineering Mechanics for the Future", is jointly hosted by the Università degli Studi di Napoli "Federico II" and the Engineering Mechanics Institute of ASCE.

EMI2026-IC brings together researchers, educators, practitioners, and students from around the world to exchange ideas and present the latest advances in engineering mechanics across the broad spectrum of civil engineering and related disciplines. The technical program reflects both the enduring foundations and the rapidly evolving frontiers of our field. Classical areas such as mechanics of materials, fracture mechanics, computational mechanics, structural mechanics, geomechanics, structural health monitoring, material science, and probabilistic methods, are integrated by emerging topics such as artificial intelligence and machine learning, digital twins, smart materials, and multiscale and multiphysics modeling. Together, these diverse themes illustrate how engineering mechanics continues to evolve while remaining firmly rooted in the fundamental principles that have long defined our discipline.

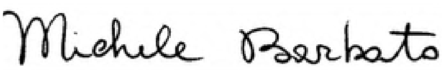
This year's program includes 22 minisymposia and five keynote sessions delivered by distinguished plenary speakers on topics of great relevance and interest to both researchers and practicing engineers. Beyond its technical program, EMI2026-IC provides an exceptional opportunity to strengthen existing collaborations, establish new international partnerships, and engage in thoughtful discussions about the future of engineering mechanics. As our discipline increasingly intersects with artificial intelligence, advanced manufacturing, sustainability, digital engineering, and resilient infrastructure, the role of engineering mechanics and its fundamentals has never been more important. I am especially pleased to welcome the many students and early-career researchers attending the conference. Their enthusiasm, creativity, and scientific curiosity will continue to drive innovation and ensure the continued vitality of our community.

I would like to express my sincere gratitude to the conference co-chairs, Professors Luigi Di Sarno (University of Liverpool), Andrea Prota (Università degli Studi di Napoli Federico II), and Paolo Gardoni (University of Illinois Urbana-Champaign), the members of the organizing committee, the minisymposia organizers, as well as the staff, sponsors, volunteers, and all participants whose hard work and dedication have made this event possible.

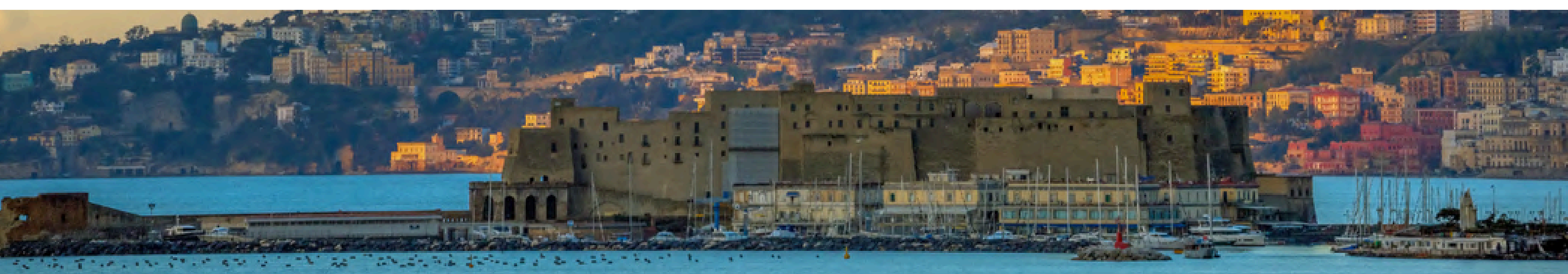
I encourage you to take full advantage of everything EMI2026-IC has to offer: attend inspiring presentations, engage in lively technical discussions, build new collaborations, reconnect with colleagues and friends, and enjoy the remarkable history, culture, and hospitality of Naples. I am confident that your participation will make this conference both professionally rewarding and personally memorable.

Thank you for joining us, and I wish you an inspiring, productive, and enjoyable conference.

Warm Regards,



Michele Barbato
Ph.D., P.E., F.ASCE, F.SEI, F.EMI



Welcome Message from the EMI 2026-IC Co-Chairs

Luigi Di Sarno, PhD, MSc, DIC, FIStructE
Reader, Department of Civil and Environmental Engineering, School of Engineering University of Liverpool, UK and Associate Professor, Department of Structures for Engineering and Architecture, Università degli Studi di Napoli Federico II

Paolo Gardoni, Ph.D., A.M.ASCE. F.EMI
Professor and an Excellence Faculty Scholar
Department of Civil and Environmental Engineering
University of Illinois Urbana-Champaign

Andrea Prota, Ph.D.
Full Professor and Dean of Polytechnic and Basic Sciences School
Università degli Studi di Napoli Federico II

Dear Colleagues,

We are pleased to welcome you to the Engineering Mechanics Institute 2026 International Conference (EMI 2026 IC), the annual international flagship conference on engineering mechanics and probabilistic methods of the American Society of Civil Engineers (ASCE). The Conference is hosted by the Università degli Studi di Napoli Federico II in Naples, Italy.

The conference brings together scholars from around the world to exchange and disseminate the most recent developments in engineering mechanics and probabilistic methods across wide-ranging fields related to the discipline of Civil Engineering, understood in the broadest sense, including industry applications of engineering mechanics. Indicative scientific topics include probabilistic mechanics, data-driven methods, structural health monitoring, computational mechanics, multiscale and multiphysics, geomechanics and geomaterials, biomechanics and bio-inspired engineering, fluid mechanics, damage and fracture mechanics, and mechanics of materials and material science.

We wish you a successful conference and an enjoyable stay in Naples.

Sincerely,
EMI 2026-IC Conference Co-Chairs

EMI Board of Governors

Michele (Mike) Barbato
Ph.D., P.E., F.ASCE, F.SEI, F.EMI
University of California, Davis
President, Engineering Mechanics Institute

Alexandros Taflanidis, Ph.D., M.ASCE
University of Notre Dame
Vice-President

Arif Masud, Ph.D., F.EMI, M.ASCE
University of Illinois Urbana-Champaign
Past-President

Chloé Arson, Ph.D., M.ASCE
Cornell University
Treasurer

Raimondo Betti, Ph.D., M.ASCE
Columbia University

Megan Hart, Ph.D., CCRMP
Willis Re

Michael C Hillman, Ph.D., M.ASCE
Karagozian & Case, Inc.

Pania Newell, Ph.D., M.ASCE
University of Utah

Special Programs

Welcome Reception

Tuesday, September 1, h. 19:30 | 21:00
Venue: Yacht Club Rari Nantes
Address: Via Scogliera Santa Lucia

The venue is located on the seafront at walking distance from the Congress Centre just in front of the Hotel Excelsior and behind the big, white fountain shown on the picture.

Dress code: *smart casual (no shorts and sandals for men, long and short sleeved shirts or t-shirts are allowed)*

Social Dinner (for Full registrations or with ticket)

Thursday, September 3, h. 20:00 | 22:30
Venue: Hotel Royal Continental
Address: Via Partenope, 38
Main restaurant Mezanine Floor
Dress code: *smart casual*

Tickets can be still purchased onsite until September 1 at h. 19.00.
Please contact the Secretariat at the desk.

Keynote Speakers

Armen Der Kiureghian, P.E., NAE, F.EMI, M.ASCE
President Emeritus, American University of Armenia
Taisei Professor of Civil Engineering Emeritus, University of California, Berkeley

Response Spectrum Methods in Earthquake Engineering

The presentation will provide the random vibrations bases for the commonly used response spectrum method in earthquake engineering. The presentation will start with a description of the widely used CQC modal combination rule that is included in most design codes. The assumptions behind this method and its limitations will be described. The presentation will then focus on extensions of the CQC rule to (a) structures with high-frequency modes, (b) estimation of total floor acceleration, (c) multicomponent ground motions, (d) vector-valued responses, (e) multi-support excitations, (f) non-classically damped structures, and (g) generation of floor response spectra. Example applications in each case will be presented.

Mauro Ferrari, Ph.D.
President and CEO
BrYet US, Inc.

Engineering the Mechanics of Cancer Therapeutics

Based on the principles and methods of engineering mechanics, we formulated and validated a mathematical framework for the molecular transport phenotype of lung and liver cancers. Since these organs serve a primary function of molecular transport in the body, it is natural that their cancer counterpart is essentially a “hijacked” version of their function in health. It derives its key properties (“phenotypical nodes”) from the underlying physiology, largely irrespective of the cancer-associated molecular mutations. A cancer without these transport characteristics cannot proliferate uncontrollably, nor can it further metastasize. Thus, it is no longer a cancer. In conjunction with a broad range of experiments both in laboratories and on preclinical models of cancer, over the years, this mathematical framework (“Transport Oncophysics”) served to identify the key phenotypical nodes of molecular mass transport in cancers of the lungs and liver. These nodes span a dimensional range of multiple orders of magnitude, from the centimeter level (microvascular site recognition, vascular trans-endothelial transport) to the millimeter (microenvironmental migration) to the nanometer (cellular membrane uptake, intracellular traffic, endosomal escape, and nuclear penetration). Concurrently, and again guided by the mathematical findings, we developed multi-component ("composite") therapeutic agents that can act in a prescribed time sequence on all of these nodes – since just targeting an incomplete set of them does not yield the desired therapeutic efficacy. Enabled by a mathematically designed multi-step mechanism of transport, which sequentially targets the key nodes of the molecular transport phenotype of cancer of the lungs and liver, ML-016 was demonstrated to reproducibly yield complete cure rates of 60-80% in multiple preclinical models of metastatic cancer to the lungs and liver. These unprecedented efficacy findings, together with suitable results of regulatory-level safety and toxicity studies, and the development of clinical-grade manufacturing protocols formed the basis for our application for the beginning of clinical studies of Phase I/II in patients with any type of malignancy of the lung and liver, both primary and metastatic from any organ. The authorization to start these clinical trials was granted by the regulatory agencies of Australia in September, 2025. In this presentation, I will review key steps of our 30-year journey from mathematical modelling of cancer to the clinical use of ML-016 and will present our most recent data. The fundamental role of engineering mechanics as guidance in this journey will be highlighted.

Ahsan Kareem, Ph.D., NAE, F.EMI, Dist.M.ASCE
Robert M. Moran Professor of Engineering
Director, NatHaz Modeling Laboratory
University of Notre Dame

Mechanics of Dynamic Wind Effects: Fundamentals to Frontiers

There is a recent trend in the escalation of the extremes of natural hazards around the globe, with an emphasis on meteorological hazards. Over the last several decades, wind engineering, a multi-disciplinary subject involving engineering meteorology, fluid dynamics, structural dynamics, structural engineering, probabilistic methods, and design has addressed the challenges posed by extremes in winds of synoptic and non-synoptic origins. During this period, we have seen extraordinary advances in experimental facilities, instrumentation, and data acquisition and management. These advances have enabled us to build a cadre of civil infrastructure that meets some of the challenges posed by extreme windstorms. Yet there remain several frontiers that still need to be addressed. Fortunately, amidst these challenges, there are new opportunities to complement our existing capabilities as the burgeoning growth in computational hardware/resources and parallel computational advances, coupled with data analytics and AI-based schemes, e.g., machine learning, holds the promise of expanding our modeling, simulation, and analysis capacity far beyond what our current conventional schemes offer. This presentation provides a synopsis of the challenges posed by extremes and expands on new computational opportunities to address emerging challenges in building resilient and sustainable civil infrastructure as we shift from code-based and performance-based to resilience-based design.

Gianluca Cusatis, F.EMI, M.ASCE
Professor of Civil and Environmental Engineering and Mechanical Engineering
Northwestern University

Computational Modeling of Infrastructure Materials in the Era of Artificial Intelligence

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

The second part of the presentation will discuss recent work coupling LDPM with Machine Learning (ML) techniques for several applications, including fast parameter identification, fragmentation characterization, and macroscopic constitutive modeling from fine-scale computational data. For parameter identification, the presentation will show results obtained by exploiting ML to obtain metamodels for typical laboratory tests for concrete, namely unconfined compression test, hydrostatic test, and three-point bending test. By using these ML metamodels the computational cost for a typical LDPM parameter optimization task is reduced by several orders of magnitude without sacrificing accuracy in the optimized parameters. The second ML study focuses on predicting and quantifying fragmentation phenomena under high impulsive dynamic loading via an innovative unsupervised learning clustering technique to identify and characterize mass and velocity of fragments. Results show excellent agreement with some available experimental data. A third ML application that will be discussed is relevant to the formulation of a macroscopic tensorial constitutive equation via the ML interpolation of a large database of homogenized LDPM response obtained with randomly generated strain histories featuring complex loading-unloading-reloading histories. The study highlights the limitations of methods that have been proposed in the literature but that have been only applied to relatively simple material behavior such as elasticity and classical plasticity. Finally, the presentation will conclude by discussing some current and, most importantly, potential future work adopting disruptive computational technologies that are expected to transform material modeling research and accelerate new discoveries. We will show the results of an exercise in which we challenged a certain class of ML methods to discover the non-locality of strain-softening response of concrete specimens subject to tensile fracture. This simple exercise demonstrates the superiority and accuracy of ML methods to analyze and interpolate data as well as to discover hidden information in data. At the same, it also highlights the inherent difficulty of providing physical interpretation of ML discoveries and the danger of using ML methods to extrapolate outside the available data.

Antonina Pirrotta, Ph.D., P.E., F.EMI, F.ASCE
Professor of Mechanics of Solids and Structures
Head of Ph.D. School of UNIPA, Engineering Department
Università degli Studi di Palermo

Two Minds, One Question: A Meeting Between Leonardo da Vinci and Feynman in Mechanics

Modeling and simulation are becoming increasingly important enablers for the analysis and design of complex systems. The connection between mathematics and reality is just experimental tests. The latter makes the difference between mathematical method and scientific method, that is experimental tests for validation is an important step of the scientific method. The scientific community generally agrees on the following classification of method components.

- Characterizations
- Hypotheses
- Predictions
- Experiments

The experiments is as important as theoretical formulation. Once predictions are made, they can be sought by experiments.

The purpose of an experiment is to determine whether observations of the real world agree with or conflict with the predictions derived from a hypothesis. If they agree, confidence in the hypothesis increases; otherwise, it decreases.

It is not easy to perform experiments especially for validating theory. Experiments should be designed to minimize possible errors, through the use of appropriate scientific controls. Furthermore, failure of an experiment does not necessarily mean the hypothesis is false. Experiments always depend on several hypotheses, e.g., that the test equipment is working properly, and a failure may be a failure of one of the auxiliary hypotheses.

However, performing experimental tests is time and money consuming then in my opinion one needs a mathematical model consistent with reality in such a way that mathematical model and simulation may can be considered as a virtual test.

In application domains such as structural design, automotive design, mechanical design, vibration control, biomechanics, the notion of a virtual experiment is a valuable tool for checking and optimizing extensively the complex designs before a realization is ever made. This "doing it right the first time" leads to tremendous cost savings and improved quality.

To aim at this, it is compulsory to introduce mathematical formulation binding real behaviour. Once this theoretical formulation is reliable having confirmed experimental tests, then one can realize virtual experimental results. For instance, dealing with vibration control passive systems: Do we have VIRTUAL EXPERIMENTS?

Under the Auspices of

COMUNE DI NAPOLI

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

reluis

ORDINE INGEGNERI NAPOLI

With the support of

PSW INTEGRITY

BOVIAR

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

Organizing Secretariat

mcm EVENTI E CONGRESSI

Rione Sirignano, 5 - 80121 Napoli, Italy
ph. + 39 081 7611085
email: mcm@mcmcongressi.it
www.mcmcongressi.it

EMI Awards

EMI 2026-IC is proud to present

Armen Der Kiureghian, Ph.D, M.ASCE

with the 2026 Nathan M. Newmark Medal

held jointly with the Structural Engineering Institute of ASCE

for fundamental contributions to earthquake response spectrum analysis, random vibrations, structural reliability, stochastic modeling of ground motions, computational stochastic mechanics and finite-element reliability methods, structural response to spatially varying excitations, and seismic fragility of structural components and systems.

EMI Class of 2026 Fellow

M Ahmer Wadee, Ph.D., M.ASCE

Professor

Imperial College London

General Information

CONFERENCE VENUE

Congress Centre
University of Naples Federico II
Via Partenope, 36 - 80121 Napoli, Italy

REGISTRATION DESK & CONFERENCE SECRETARIAT

Location: Congress Centre, ground floor

Opening times:

- **Tuesday, Sept 1st**: from h. 17.00 to 19.30
- **Wednesday, Sept 2nd**: from h. 08:00 to 18:00
- **Thursday, Sept 3rd:** from h. 08:00 to 18:00
- **Friday, Sept 4th:** from 08:00 to 14:00

REGISTRATIONS

- ASCE/EMI Member (Full Registration): Early € 820 | Regular € 920 | Late € 1.100
- Non-Member (Full Registration): Early € 920 | Regular € 1.020 | Late € 1.200
- Student: Early € 580 | Regular € 680| Late € 880
- Student Banquet (1 per registration): Early € 90 | Regular € 90| Late € 100
- Accompanying Persons (welcome reception and banquet only): Early € 180 | Regular € 180| Late € 200

Member and Non-Member registration fee includes participation in the scientific sessions, coffee breaks and lunches according to the program, Welcome Reception on Sept. 1, Banquet on Sept. 3, conference kit and the Book of Abstracts (Electronic).

Student registration fee includes participation in the scientific sessions, coffee breaks and lunches according to the program, Welcome Reception on Sept. 1, conference kit and the Book of Abstracts (Electronic).

General Information

NAME BADGES

For identification purpose and admission to the conference venue and to social events, badges are expected to be worn at all times.

CERTIFICATE OF ATTENDANCE

The certificate of attendance will be sent by email to all registered participants at the end of the Conference.

MEALS

Coffee breaks and lunches will be served according to the program schedule at the Congress Centre, first floor.

GUIDELINES FOR ORAL PRESENTATIONS

Presentations should last no longer than 15 minutes to allow 5 minutes for questions and changeover to the next speaker. All screens are in widescreen (16:9) format.

Each speaker is requested to bring along the presentation on a USB pen and to upload the presentation in the room which is assigned to his/her presentation at least 30 minutes before the session starts.

AUDIO-VISUAL EQUIPMENT

Presentation rooms are equipped with projectors for computer-based presentations. Presentations should be prepared in PowerPoint or PDF.

Presenters will be provided with a remote controller, with integrated laser pointer that can be used to advance slides in PowerPoint. Slides with movies (format .MOV or MP4) must be checked for playback on the laptop.

For Mac users: Power Point slides are normally compatible. If you use “Keynote” please take care that the file is converted in PDF.

The use of one’s personal laptop is not permitted.

Network:
guestpartenope

Password:
xs4093001

SCAN to
download the program

SCAN to
download the APP

Program outline

	Venue **Congress Centre University "Federico II" - Via Partenope n. 36, Naples (Italy)**			
	September 1			
17:00 - 19:30	Registrations Congress Centre “Federico II"			
19:30 - 21:00	*Welcome Reception* Yacht Club Rari Nantes Via Scogliera Santa Lucia, Napoli			
	September 2			
from 08:00	*Registrations*			
	Main Room			
09:00 - 09:30	*Opening remarks*			
09:30 - 10:30	*Keynote Lecture* "Response Spectrum Methods in Earthquake Engineering" **Armen Der Kiureghian** *Chair*: Alessandro Contento			
10:30 - 11:00	*Coffee Break*			
	Main Room	**Room A**	**Room B**	**Room C**
11:00 - 12:20	**MS1a - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS2 - Modeling and Simulation of Complex Engineering Systems** *Chair:* Paul Gharzouzi	**MS3a - Advances in Structural and Geotechnical Engineering** *Chair:* Alessandro Contento	**MS4a - Advancements in Multiphysics Simulations** *Chair:* Antonio Cibelli
12:30 - 13:30	*Lunch*			
	Main Room			
13:30 - 14:30	*Keynote Lecture* "Engineering the Mechanics of Cancer Therapeutics" **Mauro Ferrari** *Chair:* Lori Graham-Brady			
	Main Room	**Room A**	**Room B**	**Room C**
14:30 - 15:50	**MS1b - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS5a - Mobile Sensing for Intelligent Inspection** *Chair:* Xudong Jian	**MS3b - Advances in Structural and Geotechnical Engineering** *Chair:* Alessandro Contento	**MS4b - Advancements in Multiphysics Simulations** *Chair:* Antonio Cibelli

16:00 - 16:30	*Coffee Break*			
	Main Room	**Room A**	**Room B**	**Room C**
16:30 - 18:10	**MS6 - Hybrid Methods for Computational Solid Mechanics** *Chair:* Panos Pantidis	**MS5b - Mobile Sensing for Intelligent Inspection** *Chair:* Xudong Jian	**MS7 - Wind Engineering** *Chair:* Khaled Faiaz	**MS8 - Latest Advancements on Structural and Infrastructure Robustness** *Chairs:* Leandro Iannacone, Fulvio Parisi
	September 3			
	Main Room	**Room A**	**Room B**	**Room C**
08:30 - 10:00	**MS1c - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS9a - Machine Learning Techniques for Structural Mechanics** *Chair:* Cristoforo Demartino	**MS10a - Structural instabilities: From destructive to constructive** *Chair:* Ahmer Wadee	**MS11a - Advances in Passive, Active and Semi-Active Structural Control** *Chairs:* Nicolò Vaiana, Daniele Losanno
	Main Room			
10:00 - 11:00	*Keynote Lecture* "Mechanics of Dynamic Wind Effects: Fundamentals to Frontiers" **Ahsan Kareem** *Chair:* Leandro Iannacone			
11:00 - 11:10	*Sponsored talk by BOVIAR srl* "Wide Network Bridge Monitoring: Operational Hurdles and Insights"			
11:10 - 11:30	*Coffee break*			
	Main Room	**Room A**	**Room B**	**Room C**
11:30 - 12:50	**MS1d - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS9b - Machine Learning Techniques for Structural Mechanics** *Chair:* Cristoforo Demartino	**MS10b - Structural instabilities: From destructive to constructive** *Chair:* Ahmer Wadee	**MS11b - Advances in Passive, Active and Semi-Active Structural Control** *Chairs:* Nicolò Vaiana, Daniele Losanno
13:00 - 14:00	*Lunch*			
	Main Room			
14:00 - 15:00	*Keynote Lecture* "Computational Modeling of Infrastructure Materials in the Era of Artificial Intelligence" **Gianluca Cusatis** *Chair:* Paul Gharzouzi			

<table>
<tr><td>15:00 - 15:30</td><td colspan="4">Coffee break</td></tr>
<tr><td></td><td>Main Room</td><td>Room A</td><td>Room B</td><td>Room C</td></tr>
<tr><td>15:30 - 16:10</td><td rowspan="3">MS12 - Smart Composite Materials for Structural Health Monitoring in Civil Engineering
Chair: Paolino Cassese</td><td rowspan="3">MS9c - Machine Learning Techniques for Structural Mechanics
Chair:
Cristoforo Demartino</td><td rowspan="2">MS10c - Structural instabilities: From destructive to constructive
Chair: Ahmer Wadee</td><td rowspan="3">MS13 - Structural Dynamics and More!
Chair:
Antonina Pirrotta</td></tr>
<tr><td>16:10 - 17:10</td></tr>
<tr><td>16:10 - 17:10</td><td>MS15 - Creep Modeling and Design Optimization in Concrete Materials and Structures
Chair: Luigi Di Sarno</td></tr>
<tr><td>17:10 - 18:30</td><td>MS16a - Probing Materials at Small Scales
Chair: Luis Zelaya</td><td>MS14 - Masonry and Timber Structures from Heritage to Engineered Systems
Chair: Leandro Iannacone</td><td></td><td></td></tr>
<tr><td>20:00 - 22:00</td><td colspan="4">Social Dinner
Hotel Royal Continental - Main Restaurant, Mezanine floor
Via Partenope, 38</td></tr>
</table>

	September 4			
	Main Room	**Room A**	**Room B**	**Room C**
08:30 - 10:00	**MS16b - Probing Materials at Small Scales** *Chair:* Luis Zelaya	**MS17 - Machine learning in structural dynamics and earthquake engineering** *Chair:* Alessandro Contento	**MS18 - Perspectives on Structural Dynamics and Vibration Control** *Chairs:* Francesco Paolo Pinnola, Salvatore Sessa	**MS19 - Structural Risk Assessment and Monitoring Warning** *Chair:* Marco Faggella
	Main Room			
10:00 - 11:00	*Keynote Lecture* "Two Minds, One Question: A Meeting Between Leonardo da Vinci and Feynman in Mechanics" **Antonina Pirrotta** *Chair:* Longjun Xu			
11:00 - 11:30	*Coffee break*			
	Main Room	**Room A**	**Room B**	
11:30 - 13:00	**MS21 - Single-and Multi-Risk Analysis of Civil Infrastructures** *Chairs:* Andrea Miano, Fulvio Parisi	**MS20 - Mechanistic Digital Twins of Full-Scale Structures: From Data to Models** *Chair:* Rodrigo Sarlo	**MS22 - Visualized Geotechnical Engineering Computational Mechanics** *Chair:* Longjun Xu	
	Main Room			
13:00 - 13:15	*Closing*			

SCIENTIFIC PROGRAM

EMI ASCE

Università degli Studi di Napoli Federico II

DiSt Department of Structures for Engineering and Architecture

DiSt 2023-2027 DIPARTIMENTO DI ECCELLENZA MUR

	Venue **Congress Centre University "Federico II" - Via Partenope n. 36, Naples (Italy)**
	September 1
17:00 - 19:30	Registrations Congress Centre University "Federico II"
19:30 - 21:00	*Welcome Reception* Yacht Club Rari Nantes Via Scogliera Santa Lucia, Napoli
	September 2
from 08:00	Registrations
	Main Room
09:00 - 09:30	*Opening remarks*
09:30 - 10:30	*Keynote Lecture* "Response Spectrum Methods in Earthquake Engineering" **Armen Der Kiureghian** *Chair:* Alessandro Contento
10:30 - 11:00	*Coffee Break*

	Main Room	Room A	Room B	Room C
11:00 - 12:20	**MS1a - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS2 - Modeling and Simulation of Complex Engineering Systems** *Chair:* Paul Gharzouzi	**MS3a - Advances in Structural and Geotechnical Engineering** *Chair:* Alessandro Contento	**MS4a - Advancements in Multiphysics Simulations** *Chair:* Antonio Cibelli
11:00 - 11:20	Accurate Stress Intensity Factor Evaluation using Virtual Grid-based Stress Recovery (VGSR) and Interaction Integral *Kyoungsoo Park, Nastaran Movahed, Jong Yeop Kim* (226)	Digital Twin–Enabled Automation of Marshalling Yards for Adaptive and Efficient Single Wagonload Services *Boban Djordjevic, Evelin Krmac* (80)	Seismic Resilience Assessment of Piles Subjected to Liquefaction-Induced Lateral Spreading *Hessam Yazdani, Davide Forcellini, Faramarz Ranjbar, Ali Asgari, Mohsen Bagheri* (124)	A 3D finite element coupled thermo-hygro-mechanical and neutron diffusion model for neutron-induced expansion of concrete at the mesoscale *Abderrahmane Lahmar, Benoît Bary, Tulio Honorio* (50)

September 2

	Main Room	Room A	Room B	Room C
11:20 - 11:40	A virtual element formulation based on reduced integration and its perspective regarding damage simulations *Njomza Pacolli*, *Jannick Kehls*, *Stefanie Reese*, *Hagen Holthusen* (56)	A State-of-the-Art Finite Element Model for Train Derailments Steven W. Kirkpatrick, *Paul Gharzouzi*, *Chen-Yu Lin*, *Christopher P.L. Barkan*, *Paolo Gardoni* (126)	UHPC for Advancing Structural Resilience of Buildings, Bridges, and Nuclear Infrastructure *Mohamed A. Moustafa* (23)	Implementation Of A Dynamic Particle Packing Concept For Derivation Of Particle-Based Mesoscopic-Discrete Models *Saeid Mehrpay*, *Jelle Billiet*, *Daniele Pelessone*, *Jan Vorel*, *Roman Wan-Wendner* (66)
11:40 - 12:00	Linking hardwood microstructure to stiffness and microstresses around vessels *Jakob Hofegger*, *Markus Königsberger*, *Sebastian Pech*, *Josef Füssl* (69)	Techno-economic feasibility study of district-integrated rooftop urban ice rink: Computational Modeling of District Energy Integration *Reza Chehrazi*, *Jan-Olof Dalenbäck*, *Seidpooyan Ghafoori*, *Anders Strand* (216)	Wind-Induced Torsional Loads on Irregular Low-Rise Buildings *Mahmoud Abdallah*, *Omar Abdallah*, *Rani Alsayegh*, *Zisis Ioannis* (58)	Multiphysics Response of Fiber-Reinforced Concrete Under Extreme Thermal Loading: A Review *Nunzia Gargiulo*, *Antonio Cibelli*, *Donatella de Silva*, *Emidio Nigro* (150)
12:00 - 12:20		Experimental and Numerical Investigation of Flow Separation Phenomena in Dual-Supersonic Nozzles under Over-Expanded Operating Conditions *Hamaidia Walid*, *Yahiaoui Toufik*, *Bendine Kouider*, *Hiber Houssam Eddine Nadir* (217)	Characterization Testing of Friction Pendulum Bearings with Advanced Axial Force Control *Yunbyeong Chae*, *Chunghyun Lee* (106)	A Discrete Multiphysics Model for Chloride Penetration in Damaged UHPC *Antonio Cibelli*, *Liberato Ferrara*, *Giovanni Di Luzio* (153)
12:30 - 13:30	*Lunch*			
	Main Room			
13:30 - 14:30	*Keynote Lecture* "Engineering the Mechanics of Cancer Therapeutics" **Mauro Ferrari** *Chair:* Lori Graham-Brady			

September 2				
	Main Room	Room A	Room B	Room C
14:30 - 15:50	**MS1b - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS5a - Mobile Sensing for Intelligent Inspection** *Chair:* Xudong Jian	**MS3b - Advances in Structural and Geotechnical Engineering** *Chair:* Alessandro Contento	**MS4b - Advancements in Multiphysics Simulations** *Chair:* Antonio Cibelli
14:30 - 14:50	Constitutive Models for 2D Nanomaterials Subjected to Biaxial Loading *Shahbaz Paramban, John Sellinger, Parker Cain, Jesse Hackmann, Hessam Yazdani* (99)	Acousto-ultrasonic Based Structural Health Monitoring in Corrosion Detection *Goldaran Reza* (14)	Probabilistic DEM Investigation of Rubber–Soil Mixtures for Optimizing Shallow Foundation Performance *Fedor Maksimov, Alessandro Contento, Bruno Briseghella, Pierfrancesco Cacciola* (154)	Multi-Physics Coupling Analysis of Concrete Beams Under Complex Loads and Carbonation *Li Zhu, Jia-Huan Li* (162)
14:50 - 15:10	Numerically Supported Development for Concrete Shear Fatigue Testing under Varying Normal Actions *Carlos Arboleda, Mario Aguilar, Alexander Scholzen, Rostislav Chudoba* (110)	Intelligent Damage Identification of Stay Cables Based on Computer Vision and Multi-Modal Fusion Neural Networks *Li Zhu, Jia-Huan Li, Zhi-Ruo Cui* (161)	Advancing the Modeling of Metallic Foam Claddings for Blast Mitigation: From Shock Front Theory to Discrete Spring-Lumped-Mass Modeling *Wattad Ola, Hezi Y. Grisaro* (125)	Probabilistic Model and Reliability Analysis of Spalling for Concrete Elements in Fire Conditions *Enrico Cardellino, Marco Andreini, Donatella de Silva, Saverio La Mendola, Emidio Nigro* (207)
15:10 - 15:30	Modified non-local damage model: Resolving spurious damage evolution Roshan Philip Saji, Panos Pantidis, Mostafa E. Mobasher (139)	Robotic Mobile Sensing for Scalable Walkability Assessment of Urban Pedestrian Walkways – Case Studies from Singapore *Xudong Jian, Kresimir Friganovic, Navrag Singh* (167)	Combinatorial cyber-physical shape optimization for tall buildings using hybrid aerodynamic strategies *Wei-Ting Lu, Brian M. Phillips, Zhaoshuo Jiang* (184)	Robust Calibration of Constitutive Models Based on Full-Field Data *Lennart Linden, Karl Kalin, Jörg Brummund, Brain Riemer, Markus Kästner* (8)
15:30 - 15:50		Adaptive refinement of railway bridge modal parameters from on-board monitoring data *Charikleia Stoura, Eleni Chatzi* (168)	Rolling and impact dynamics of quasi-globular solids for the protection of the Millefiori Vesuvian Cups *Ester Sallicandro, Roberto Serpieri* (112)	Enhanced Fracture Resistance in Aperiodic Monotile Composites with Bio-Inspired Interlocking Interfaces *Hongru Zhang, Yuanpeng Liu, Jiaming Ma, Ngoc San Ha, Yi Min Xie* (160)

September 2				
16:00 - 16:30	*Coffee Break*			
	Main Room	**Room A**	**Room B**	**Room C**
16:30 - 18:10	**MS6 - Hybrid Methods for Computational Solid Mechanics** *Chair:* Panos Pantidis	**MS5b - Mobile Sensing for Intelligent Inspection** *Chair:* Xudong Jian	**MS7 - Wind Engineering** *Chair:* Khaled Faiaz	**MS8 - Latest Advancements on Structural and Infrastructure Robustness** *Chairs:* Leandro Iannacone, Fulvio Parisi
16:30 - 16:50	Accelerating phase-field fracture simulations with the Integrated Finite Element Neural Network (IFENN) *<u>Panos Pantidis</u>, Fouad Amin, Diab Abueidda, Mostafa E. Mobasher* (49)	Edge-AI-driven mobile sensing platform for real-time pavement distress assessment *<u>Diego Rossini</u>, Leonardo Iacussi, Emanuele Zappa, Alfredo Cigada, Paolo Chiariotti* (175)	Tornado-like Vortices Modeling in Straight-line Simulators: An Alternative Approach *Mohammad Abid Hasan, <u>Faiaz Khaled</u>, Franklin T. Lombardo* (119)	Reliability-based Progressive Collapse Analysis of RC Frame Structures via the Global Factor Method *Luchuan Ding, <u>Fulvio Parisi</u>, Xiaohui Yu, Nian Lin* (37)
16:50 - 17:10	Solving Elasto-Plastic Layered Contacts via Physics-Data Hybrid Neural Network *<u>Shaoqi Huang</u>, Haoyu Gu, Siyang Song, Chongpu Zhai, Minglong Xu* (61)	From Component-level Information to Portfolio-scale Structural Resilience Assessment: A Measurement-Informed BIM2Struct Digital Twin Framework *<u>Huangbin Liang</u>, Kostas Vlachas, Eleni Chatzi* (180)	Advancing Debris Modeling for Tornadoes and Tornado Risk Assessment *Sung Min Moon, <u>Franklin T. Lombardo</u>, David Bodine* (221)	Data augmentation framework for black swan structural failure modes under earthquakes *Jungho Kim, <u>Taeyong Kim</u>* (227)
17:10 - 17:30	A Unified Differentiable Computational Mechanics Framework: From Physics-Informed Neural PDE Solvers to Neural-Embedded Material Point Methods *<u>Yuming Zhang</u>, Jiaji Wang, Mingyu Wang, Xiaoge Tian, Si Fu* (65)	Development of Scan-to-BIM Based Technology for Automated Extraction and 3D Visualization of Bridge Surface Damage Information *<u>Gun Mo Kang</u>, Sangyun Song, Gichun Cha, Dongkyu Lim, Seunghee Park* (195)	Towards fragility curves for buildings subjected to non-synoptic like winds generated through an active-controlled multi-blade flow device *<u>Rigoberto Morales Hernández</u>, Stefano Brusco, Alessio Ricci, Maria Pia Repetto* (223)	The Value of Information of Robustness under Adversarial Actions *<u>Leandro Iannacone</u>, Alex Sixie Cao* (142)

September 2

	Main Room	Room A	Room B	Room C
17:30 - 17:50	Exact Boundary Conditions Physics-informed Solver for Elastodynamics *Xiaoge Tian*, *Jiaji Wang, Yuming Zhang, Si Fu, Mingyu Wang* (83)	LiDAR–Vision Fusion for Automated Digital Twin Updating of 3D Defects *Dongyoung Ko*, *PaPa Win Aung, Khoa Tran Dang Vo, Changjun Lee, Seunghee Park* (196)	Turbulent Boundary Layer Height Scales in Hurricanes *Kishore R. Sathia*, *Marco G. Giometto* (224)	Probabilistic Robustness Assessment of Existing RC Buildings Subjected to Debris-Flow Impact *Federica Rauseo*, *Ludovico Alberico Grieco*, *Fulvio Parisi* (181)
17:50 - 18:10	Integrated Finite Element Neural Networks (I-FENN) for Efficient Multiphysics Simulation *Mostafa E. Mobasher*, *Panos Pantidis, Diab W. Abueidda, Habiba Eldababy, Fouad Amin* (140)	Wavelet-Based Crack Detection Using Improved Phase-Based Optical Flow *Sung-min Eom*, *Dong-heon Yang, Sang-heon Lee, Kyung Ho Sun, Yun-ho Shin* (201)		Experimental Investigation of External Near-Surface Mounted Steel Wire Wrapping for Shear Strengthening of Reinforced Concrete Beams *Mohamed Ghala*, *Galal Elsamak, Rania Sira, Ashraf Ashour* (225)

September 3

	Main Room	Room A	Room B	Room C
08:30 - 10:00	**MS1c - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS9a - Machine Learning Techniques for Structural Mechanics** *Chair:* Cristoforo Demartino	**MS10a - Structural instabilities: From destructive to constructive** *Chair:* Ahmer Wadee	**MS11a - Advances in Passive, Active and Semi-Active Structural Control** *Chairs:* Nicolò Vaiana, Daniele Losanno
08:30 - 08:50	Comparison of Begley–Landes (1972) and ASTM D8044 Multiple Specimen Methods for Determining the Critical J-Integral of Asphalt Concrete *Abhilash Vyas*, *Ramez Hajj* (156)	Reduced-Dataset Machine Learning for Blast Damage Assessment of RC Columns: A Multi-Step Combination Method *Yeeun Kim*, *Subin Kim, Jiuk Shin* (39)	Bifurcations in the lateral thermal buckling of subsea pipelines *D. Liu*, *Gert Van der Heijden* (46)	Dynamic Behavior of Hysteretic Mechanical Systems Subjected to External Pulse Forces *Nicolò Vaiana*, *Raffaele Capuano* (10)

September 3

	Main Room	Room A	Room B	Room C
08:50 - 09:10	A Data-driven multiscale Lattice Discrete Particle Model (LDPM) for digital twin modeling of concrete structures *Baixi Chen, Alessandro Fascetti* (159)	Blast Performance Evaluation of Reinforced Concrete Columns Using Conditional Generative Adversarial Networks *Haewon Kang, Eunbin Son, Jiuk Shin* (40)	Localisation of Deformation in Metallic Kirigami *Amanpreet Singh, Marcelo A. Dias, Martin G. Walker* (51)	A 3d Printed Meta-Basement for Vibration Control: Preliminary Analytical, Numerical, and Experimental Results *Salvatore Vecchiè, Raffaele Capuano, Fabrizia Cilento, Daniele Losanno, Nicolò Vaiana* (11)
09:10 - 09:30	Variance propagation in a mesoscale discrete model of concrete fatigue *Miroslav Vořechovský, Adam Sklenář* (179)	Generative Model for Predicting Nonlinear Backbone curves of Reinforced Concrete Columns *Youngmin Song, Taehyeon Kim, Jiuk Shin* (41)	Tailored Lattices for Energy Absorption *Yuhang Liu, Anton Köllner, Andrew T. M. Phillips, M. Ahmer Wadee* (54)	On the Influence of the Hysteresis Loop Shape on the Dynamics of Rocking Systems *Raffaele Capuano, Nicolò Vaiana, Luciano Rosati* (12)
09:30 - 09:50	Comparative Analysis of Crack Driving Force for Quasi-Brittle Material Using Phase Field Model *Naqibullah Mehri, Hemam Amarjit Singh, Rimen Jamatia, Surendra Beniwal* (171)		Estimating Imperfection Sensitivity *Simon D. Guest* (57)	Achieving mechanical nonreciprocity through gap-based design *Xiang Chen, Vahid Shobeiri, Yi Min Xie* (31)
	Main Room			
10:00 - 11:00	*Keynote Lecture* "Mechanics of Dynamic Wind Effects: Fundamentals to Frontiers" **Ahsan Kareem** *Chair:* Leandro Iannacone			
11:00 - 11:10	*Sponsored talk by BOVIAR srl* "Wide Network Bridge Monitoring: Operational Hurdles and Insights" **Gianluca Galluzzo**			
11:10 - 11:30	*Coffee break*			

September 3				
	Main Room	**Room A**	**Room B**	**Room C**
11:30 - 12:50	**MS1d - Advances in Modeling of Material Damage and Fracture** *Chair:* Lampros Svolos	**MS9b - Machine Learning Techniques for Structural Mechanics** *Chair:* Cristoforo Demartino	**MS10b - Structural instabilities: From destructive to constructive** *Chair:* Ahmer Wadee	**MS11b - Advances in Passive, Active and Semi-Active Structural Control** *Chairs:* Nicolò Vaiana, Daniele Losanno
11:30 - 11:50	Monolithic, Partially Staggered, and Fully Staggered Schemes for Thermomechanically Coupled Phase-Field Fracture Simulations *Lampros Svolos, Tao Jin* (183)	Machine Learning Surrogate Models for Stochastic Structural Mechanics with Spatially Random Material Properties *Neander Mendes, Lineu Pedroso* (47)	Nonlinear Struts Under Parametric Excitation: Resonance Characterization *Yu Cheng, M. Ahmer Wadee, Christian Malaga-Chuquitaype* (79)	Experimental validation of Fiber Reinforced Elastimeric Isolators for seismic isolation of bridges with non-linear viscous dampers *Daniele Losanno, Pio Medaglia, Shiv Prakash, Giorgio Serino* (74)
11:50 - 12:10	Total Lagrangian Material Point Method for dynamic ductile fracture *Borys Zyto, Lampros Svolos, Emmanouil Kakouris* (197)	Bayesian-Driven Optimization of Recoverable Strain in Compliant Auxetic Cementitious Composites for Energy Harvesting Applications *Jinbao Xie, Branko Šavija* (77)	Testing and modelling of collapse mechanisms in cellular aluminium foams *Finian McCann, Gabrielle Marshall, Gbolahan Salako* (84)	Seismic Vulnerability Control of Steel Moment-Resisting Frames Using Optimum Multiple Friction Tuned Mass Dampers Mohsen Khatibinia, *Hessam Yazdani, Fatemehsadat Moosavinezhad, Sadjad Gharehbaghi* (98)
12:10 - 12:30	A Two-scale Framework for Multiscale Phase Field Fracture *Yangzi He, Shabnam J. Semnani* (208)	A regression model for regional-scale anomaly characterization in masonry bridges based on spaceborne radar measurements *Wael Alahmad, Said Quqa, Cristina Gentilini* (135)	Analytical investigation of the buckling behavior of sandwich structures with anisotropic/thin-walled cores *Robin Turlin, Philippe Le Grognec* (85)	Safe Reinforcement Learning for Active Train Vibration Control under Train-Bridge Interaction *Li Zhu, Yufeng Gu* (163)
12:30 - 12:50		Multi-Scale Structural Graph Neural Networks for Efficient Prediction of Structural Responses *Qilin Li, Yanda Shao, Ling Li, Hong Hao* (164)	An Analytical Approach to the Stability Design of Struts with Nonlinear Materials *M. Ahmer Wadee, Anton Köllner, Leroy Gardner* (87)	Seismic Control Performance of Structures Equipped with Active Variable Inerter-Based Tuned Mass Dampers *Chang-Ching Chang, Jer-Fu Wang* (215)

September 3				
13:00 - 14:00	*Lunch*			
	Main Room			
14:00 - 15:00	*Keynote Lecture* "Computational Modeling of Infrastructure Materials in the Era of Artificial Intelligence" **Gianluca Cusatis** *Chair:* Paul Gharzouzi			
15:00 - 15:30	*Coffee break*			
	Main Room	**Room A**	**Room B**	**Room C**
15:30 - 17:30	**MS12 - Smart Composite Materials for Structural Health Monitoring in Civil Engineering** *Chair:* Paolino Cassese	**MS9c - Machine Learning Techniques for Structural Mechanics** *Chair:* Cristoforo Demartino	**MS10c - Structural instabilities: From destructive to constructive** *Chair:* Ahmer Wadee	**MS13 - Structural Dynamics and More!** *Chair:* Antonina Pirrotta
15:30 - 15:50	Electromechanical Response of Self-Sensing Cement-Based Composites under Cyclic Loading and AC Excitation *Paolino Cassese, Luigi Cieri, Carlo Luca Schiavi, Antonio Bonati, Carlo Rainieri* (86)	Explainable Machine Learning for Corrosion Degradation Assessment of Steel Port Structures Using Atmospheric Sensor Data *Mohamed El Amine Ben Seghier, Enobong Felix Daniel, Haijie Tong, Yan Miao, Daniel Höche* (166)	Structural stability analyses with path-following techniques for semi-analytical modelling *Anton Köllner* (93)	Extended Classification and Generalized Vaiana-Rosati Model Accounting for Rate-Independent Hysteresis Loops with Evolving Shape *Nicolò Vaiana, Luciano Rosati* (15)
15:50 - 16:10	Smart Piezoelectric Bearings for Bridge-Based Vehicle Identification *Alessandro Guarnieri, Caterina Levati, Francesco Petrini* (111)	Insights on AI-driven algorithms for automated clustering of persistent scatterer-based interferometry *Sandropio Scoccola, Tony Fierro, Antonio Sandoli* (191)	Sandwich Beams Destabilizing Effect of the Load *Avi Wurf, Yeoshua Frostig, Oded Rabinovitch* (193)	Development of Industry 4.0–Compliant IoT Gear Motors *István Gábor Gyurika* (70)
16:10 - 16:30	Piezoelectric Bearings (PiBs) for Sustainable Structural Health Monitoring of bridges *Alessandro Guarnieri, Francesco Petrini* (113)	ML-enabled forward models of complex materials applications *Lori Graham-Brady, Ashwini Gupta, Indrashish Saha* (198)	**MS15 - Creep Modeling and Design Optimization in Concrete Materials and Structures** *Chair:* Luigi Di Sarno Applicability of Traditional Concrete Creep Model in Modern Concrete *Qing Wang, Xingyue Li* (53)	Dynamic Response and Scaling Constraint Mitigation for Discrete Flexible Structures in Full-Scale Rockfall Testing *Shr-Fan Yang, Tomonori Tajima, Masakazu Namba, Koichi Arakawa, Louis Ge* (72)

September 3				
	Main Room	**Room A**	**Room B**	**Room C**
16:30 - 16:50	Sensor-Enabled Geosynthetics for Stabilization and Instrumentation of Earth Systems: Development, Testing, and Multiscale Simulations *Hessam Yazdani, Kianoosh Hatami* (122)	Real-Time Reconstruction of Urban Flows via GAVI and SHRED *Josep Maria Duró, Arnau Miró, Benet Eiximeno, J. Nathan Kutz, Oriol Lehmkuhl, Ivette Rodríguez* (194)	Linking particle micromechanics to multiscale morphologies during granular creep via In-Situ X-Ray CT *Jianwei Cheng, Zhengjin Wang, Shaoqi Huang, Chongpu Zhai, Minglong Xu* (219)	Probability distribution of highly-non-Gaussian wind pressure peak factors on hyperbolic paraboloid roofs *Michele Barbato* (92)
16:50 - 17:10	Towards Self-Sensing Masonry: Development of Hybrid Carbon-Doped Conductive Mortars *Ryan Araujo de Matos, Antonella D'Alessandro, Israel Nilton Lopes Sousa, Filippo Ubertini* (211)	Mechanically Admissible Quantum and Classical Kernel Surrogates for Structural Capacity Domains *Salvatore Sessa, Luciano Rosati* (16)	Application of Genetic Algorithms to the Biaxial Design Optimization of T-Shaped Reinforced Concrete Walls *Felipe Yáñez, Fabián Rojas, Leonardo Massone* (89)	Contact Evolution and Multi-Directional Load Generation in Heavy-Haul Railway Couplers *Yazhao Wang, Wei Zhou* (157)
17:10 - 17:30	**MS16a - Probing Materials at Small Scales** *Chair:* Luis Zelaya Testing mechanical and transport properties of ITZ in Concrete *Erik Schlangen, Shan He, Magdalena Rajczakowska, Kangtai Yan, Arpan Adhikari, Branko Savija* (82)	Model-Driven Machine Learning for Efficient Seismic Damage Assessment of Industrial Non-Structural Components *Gianluca Quinci, Cristoforo Demartino (230)*		Investigating Interference Effects on Aerodynamic Loading under Tornado-Like Vortices: An LES Study *Samuel Hanson, Mohammed Abid Hasan, Faiaz Khaled* (114)

September 3				
	Main Room	**Room A**		
17.30 - 18.30	**MS16a - Probing Materials at Small Scales** Chair: Luis Zelaya	**MS14 - Masonry and Timber Structures from Heritage to Engineered Systems** *Chair:* Leandro Iannacone		
17:30- 17.50	Image-Guided Identification of Phase-Intrinsic Nanoindentation Properties in Alkali-Activated Slag–Fly Ash Binders *Markus Königsberger, <u>Luis Zelaya-Lainez</u>, Olaf Lahayne, Bernhard L. A. Pichler, Christian Hellmich* (97)	Timber pegged joints: reading in key new Eurocode 8 *<u>Antonio Sandoli</u>, Carla Ceraldi* (33)		
17:50 - 18.10	Distance-guided nanoindentation reveals mechanical changes of cell wall layers in native, infiltrated, and trans-parent wood *<u>Johanna Schindler</u>, Markus Königsberger, Luis Zelaya-Lainez, Josef Füssl* (107)	Experimental assessment and modelling of creep in Laminated Veneer Lumber (LVL) *<u>Mohsen Naghdinasab</u>, Jan T. Benthien, Sabrina Heldner, Martin Nopens, Philippe Grönquist* (78)		
18:10 - 18.30	Effect of Precipitation Agent on Hydrated Magnesium Carbonate Formation and Strength Development in Brine-Derived Brucite *<u>Inderjeet Singh</u>, Xiangyu Wang, Padmaja Krishnan, Ribal Jabbour, Asif Equbal, Kemal Celik* (185)	Deployable Timber–Cable Roof Structures for Solar-Active Stadiums *<u>Rana Nazifi Charandabi</u>, Gerardo Carpentieri, Ada Amendola, Fernando Fraternali* (169)		
20:00 - 22:00	*Social Dinner* Hotel Royal Continental - Main Restaurant, Mezanine floor - Via Partenope, 38			

September 4				
	Main Room	**Room A**	**Room B**	**Room C**
08:30 - 10:00	**MS16b - Probing Materials at Small Scales** *Chair:* Luis Zelaya	**MS17 - Machine learning in structural dynamics and earthquake engineering** *Chair:* Alessandro Contento	**MS18 - Perspectives on Structural Dynamics and Vibration Control** *Chairs:* Francesco Paolo Pinnola, Salvatore Sessa	**MS19 - Structural Risk Assessment and Monitoring Warning** *Chair:* Marco Faggella
08:30 - 08:50	In-situ X-ray Computed Tomography Characterization of Auxetic Cementitious Composites *Zhaozheng Meng, Branko Šavija* (59)	Improving Physics-Informed Neural Networks for Structural Dynamics via Mixed Lagrangian Formalism *Yixuan Zhang, Haolin Li, Christian Málaga-Chuquitaype* (25)	Structural Health Monitoring of Buildings in the Phlegraean area under volcanic Seismic Excitations *Daniela De Gregorio, Domenico Patanè, Claudio Martino, Francesca L. Perelli, Salvatore Sessa* (17)	Reliability-based calibration of Eurocode 3 partial safety factors for DED-Arc steel sections considering geometric and material variability *Wenxuan Hong, Athina Spinasa, Leroy Gardner* (202)
08:50 - 09:10	"Bio-metals" – ancient biological materials with nano-indentation size effects: Experiments and elements of manifold micromechanics *Luis Zelaya-Lainez, Friedrich S. Schuster, Stefan Manhartseder, Maximilian Landegger, Kyojiro N. Ikeda, Florian Raible, Olaf Lahayne, Stefan Scheiner, Christian Hellmich* (67)	Rapid Seismic Wave Propagation using Deep Learning Surrogates based on Tensorized Fourier Neural Operator (T-FNO) *Marco Migliavacca, Luca Brambilla, Luca Rosafalco, Chiara Smerzini, Attilio Frangi* (71)	Eigenanalysis of stress-driven nonlocal axially vibrating Bishop rods *Francesco Paolo Pinnola, Francesco Marotti de Sciarra* (95)	A Benchmark RC Building for Uncertainty Quantification and System-Level Multi-Scale Numerical Validation of Infills and Beam-Column Joints Interaction *Marco Faggella, Annalisa Napoli, Jose Melo, Aslam Faqeer Mohammad, Omar Al Shawa, Roberto Realfonzo, Michele D'Amato, Domenico Liberatore, Humberto Varum, Rosario Gigliotti*
09:10 - 09:30	Time-Resolved Neutron Tomography of Biochar-Internal Curing in Cement Paste *Liang Chen, Kemal Celik* (68)	Interpretable Physics-Informed Deep Learning for the Seismic Assessment of Rigid Rocking Response *Shirley Shen, Christian Málaga-Chuquitaype* (96)	Generalizing Motion-Based Hybrid Strategies for Seismic Control Beyond Buildings *Diana Faiella, Luigi Di Sarno, Andrea Prota, Elena Mele* (143)	Unsteady Flow Numerical Study of Local Scour around Pile Groups *Jian Guo, Chenyu Hu, Tong Wang (62)*

September 4

	Main Room	Room A	Room B	Room C
09:30 - 09:50	Multiscale modeling of basic creep of mature slag-based CEM II concrete *Maximilian Sorgner, Rodrigo Díaz Flores, Bernhard Pichler, Thomas Pilgerstorfer, Bernd Moritz, Christian Hellmich* (73)		Dispersive waves in cubic lattices: a reappraisal of Goursat surfaces *Giuseppe Ruta, Noël Challamel, Phu Huu Nguyen, Chien-Min Wang* (209)	
	Main Room			
10:00 - 11:00	*Keynote Lecture* "Two Minds, One Question: A Meeting Between Leonardo da Vinci and Feynman in Mechanics" **Antonina Pirrotta** *Chair:* Longjun Xu			
11:00 - 11:30	*Coffee break*			
	Main Room	**Room A**	**Room B**	
11:30 - 13:00	**MS21 - Single-and Multi-Risk Analysis of Civil Infrastructures** *Chairs:* Andrea Miano, Fulvio Parisi	**MS20 - Mechanistic Digital Twins of Full-Scale Structures: From Data to Models** *Chair:* Rodrigo Sarlo	**MS22 - Visualized Geotechnical Engineering Computational Mechanics** *Chair:* Longjun Xu	
11:30 - 11:50	Efficiency Assessment of Urban Road Networks Connecting Critical Nodes under Seismic Hazard *Andrea Miano, Marco Civera, Valerio De Biagi, Fulvio Parisi* (34)	Hyper-reduced order modeling of inelastic arbitrary Lagrangian Eulerian simulations for a digital twin of the road *Jannick Kehls, Stephan Ritzert, Stefanie Reese, Tim Brepols* (55)	Visualization of Disaster Mechanisms in Tunnel Structures Crossing Faults *Longjun Xu, Heng Zhang, Jie Wang* (32)	

September 4				
	Main Room	**Room A**	**Room B**	
11:50 - 12:10	A Probabilistic Framework for Multi-Hazard Bridge Assessment with Operational Downtime Estimation *Enrico Cianci, Marco Civera, Valerio De Biagi, Bernardino Chiaia* (42)	A Data-driven multiscale Lattice Discrete Particle Model (LDPM) for digital twin modeling of concrete structures *Baixi Chen, Alessandro Fascetti* (158)	A visualized computational framework for irregular granular geomaterials combining generative modeling, neural shape representation, and multiscale CFD- DEM simulation *Chenghao Li, Zhengshou Lai, Shuai Huang, Linchong Huang* (210)	
12:10 - 12:30	Bayesian Diagnostic Reliability of Dual-Source Dam-Springs Water Infrastructure under Non-Stationary Climate and Regulatory Constraints *Marco Faggella, Giampiero D'Ecclesiis, Andre R. Barbosa* (94)	Domain-Guided Probabilistic Graphical Model for Structurally Context-Aware Component Classification *Rodrigo Sarlo, Yunus Kantekin* (176)	Investigating the Dynamic Behavior of Metaconcrete with Stabilized Soil Aggregates *Giuseppina Di Chiara, Marco Miniaci, Ilenia Farina, Antonella Petrillo, Raimondo Luciano, Fernando Fraternali* (173)	
12:30 - 12:50	Optimizing Resilience of Ground-Mounted PV Support Structures under Extreme Flood Hazards *Wenzhu Li, Ashraf Osman, Hailiang Du, Mahmoud Shahbazi, Peter Matthews, Hongjian Sun* (174)		Homogenization Techniques for Granular Materials: A Critical Review *Aditya Roy Chowdhury, Mousumi Mukherjee, Arindam Dey* (178)	
	Main Room			
13:00 - 13:15	*Closing*			

EMI International Conference 2026

Napoli (Italy), 2-4 September

University of Napoli Federico II

Fundamentals in Action: Advancing Engineering Mechanics for the Future

CONFERENCE CO-CHAIRS

Luigi Di Sarno, Napoli, Italy

Paolo Gardoni, Champaign, USA

Andrea Prota, Napoli, Italy

ABSTRACT BOOK

MS1

Accurate Stress Intensity Factor Evaluation using Virtual Grid-based Stress Recovery (VGSR) and Interaction Integral

Kyoungsoo Park [a], **Nastaran Movahedi** [a] **& Jong Yeop Kim** [a]

[a] Department of Civil & Environmental Engineering, Yonsei University, Seoul, S. Korea

E-mail: k-park@yonsei.ac.kr

Abstract

The evaluation of stress intensity factors (SIFs) is critical in various engineering fields. However, a well-structured ring-shaped mesh or a special set of enrichment functions is generally needed to accurately capture SIFs. To reduce mesh generation efforts in the standard finite element analysis for complex crack geometry, the present study proposes utilizing the virtual grid-based stress recovery (VGSR) and the interaction integral method with arbitrary tetrahedral element discretization [1, 2, 3]. The key concept is that the interaction integral and associated physical quantities, including stress, are evaluated in a virtual grid domain instead of the original finite element mesh. Therefore, the use of VGSR reduces errors associated with the numerical differentiation and provides a well-shaped numerical integration domain. Several benchmark examples are solved, including an arc-shaped crack, an inclined penny-shaped crack, and a lens-shaped crack. The evaluated SIFs converge to reference solutions under mesh refinement, and the path-independence of the interaction integral is demonstrated. Furthermore, the computational results demonstrate that the proposed framework provides a similar level of accuracy compared to the standard finite element analysis with quarter-point elements in a ring-shaped mesh.

Keywords: Stress intensity factor, virtual grid-based stress recovery (VGSR), interaction integral

References:

[1] N. Movahedi, T.-S. Han, K. Park, Virtual Grid Stress Recovery (VGSR): A Substitution Method for Singular Elements Method in Stress Intensity Factor Evaluation, Int. J. Fract. (under review)

Reference to a book:

[2] N. Movahedi, J. Kim, K. Park, Stress Intensity Factor Evaluation for Non-Planar Cracks Using Virtual Grid Stress Recovery (VGSR) and Interaction Integral Methods, Adv. Eng. Softw. 212 (2026) 104042.

[3] H. Choi, H.-R. Cui, K. Park, Evaluation of Stress Intensity Factor for Arbitrary and Low-Quality Meshes Using Virtual Grid-Based Stress Recovery (VGSR), Eng. Fract. Mech. 263 (2022) 108172.

A virtual element formulation based on reduced integration and its perspective regarding damage simulations

Njomza Pacolli [a], **Jannick Kehls**[a], **Stefanie Reese** [a,b] **& Hagen Holthusen** [c]

[a] Institute of Applied Mechanics, RWTH Aachen University, Germany
[b] University of Siegen, Germany
[c] Institute of Applied Mechanics, University of Erlangen-Nuremberg, Germany

E-mail: *njomza.pacolli@ifam.rwth-aachen.de*

Abstract

The virtual element method (VEM) is an extension of the classical finite element method (FEM), designed to overcome some of its geometric limitations in examples involving crack propagation problems and contact simulations. In contrast to standard FEM, VEM can handle arbitrary polygonal and polyhedral meshes, which provides a high degree of flexibility in mesh generation and local refinement [1]. This is particularly advantageous in practical engineering applications involving complex geometries, strongly distorted elements, evolving cracks, or non-convex domains. As in reduced integration-based FEM formulations, stabilization plays a crucial role in VEM. Since the method itself yields a rank deficient stiffness matrix, specific stabilization methods are required to guarantee consistency and convergence. Various stabilization strategies have already been proposed in the literature to ensure robustness and accuracy across different problem classes [2]. For applications in solid mechanics, especially those involving material failure, it is essential to combine this geometric flexibility with advanced constitutive modeling. In particular, gradient-extended damage-plasticity models are suitable for capturing material damage. The main goal is to use the advantages of VEM to model damage. To this end, the idea of combining the VEM framework with the gradient-extended damage plasticity model for large deformations of Brepols et al. (2020) [3] is presented and possible challenges are investigated.

Keywords: damage, plasticity, virtual element method, stabilization, material failure

References:

[1] L. Veiga, F. Brezzi, A. Cangiani, G. Manzini, L. Marini, and A. Russo. Basic principles of virtual element methods, Mathemat-ical Models and Methods in Applied Sciences, 23, 2013

[2] P. Wriggers, B.D. Reddy, W. Rust, B. Hudobivnik. Efficient virtual element formulations for compressible and incompressible finite deformations, Computational Mechanics, 2017

[3] T. Brepols, S. Wulfinghoff, and S. Reese, A gradient-extended two-surface damage-plasticity model for large deformations. Int.
J. Plast. (2020) 129: 102635.

Linking hardwood microstructure to stiffness and microstresses around vessels

Jakob Hofegger[a], Markus Königsberger[a], Sebastian Pech[a], and Josef Füssl[a]

[a] Institute for Mechanics of Materials and Structures, Technische Universität Wien (TU Wien), Vienna, Austria,
E-mail: jakob.hofegger@tuwien.ac.at

Abstract

Geometrical properties of the wooden cell network at the microscale significantly influence the cross-grain mechanical properties of wood [1]. These effects can be systematically investigated using finite element (FE) simulations. A central challenge lies in generating realistic microstructural geometries that are suitable for meshing, capture the stochastic variability of wood cell architecture, and differentiate between the lignin-rich middle lamella (ML) and the cellulose-dominated cell wall regions, particularly the S2-layer.

In this study, a robust computational microstructure generator for hardwood cell architecture is developed and coupled with FE modeling. First, regular grids of cell centers are generated and subsequently distorted to introduce variability. The microstructure is then built-up using power diagrams [2] — an extension of Voronoi tessellations — combined with Bézier curves to ensure well-defined interfaces and an explicit distinction between two primary cell wall components: the middle lamella and the S2-layer. Two-dimensional FE meshes are generated with the open- source software *GMSH*, and mechanical simulations are carried out in *Ferrite/Julia* using generalized periodic boundary conditions [3]. The model is employed to establish relationships between cell microstructure and wood stiffness, as well as local microstress distributions, especially around vessels. The framework reveals that rolling shear stiffness and stiffness in both radial and tangential directions decreases with increasing geometric distortion. In contrast, stress concentrations rise significantly with distortion, particularly in the vicinity of vessels, confirming their role as structural weak points. Simulations comparing pristine and transparent wood further demonstrate stiffness enhancement due to polymer infiltration and a substantial reduction in critical stress concentrations.

Keywords: hardwood microstructure, finite element simulations, stress concentrations

References:

[1] P. Niemz, A. Teischinger, D. Sandberg. Springer Handbook of Wood Science and Technology. Springer Cham, 2023. DOI: 10.1007/978-3-030-81315-4

[2] F. Aurenhammer: Power diagrams: properties, algorithms and applications. SIAM Journal on Computing, 16 (1) (1987): 78– 96, DOI:10.1137/0216006

[3] V.-D. Nguyen, E. Béchet, C. Geuzaine, L. Noels: Imposing periodic boundary condition on arbitrary meshes by polynomial interpolation, Computational Materials Science 55 (2012) 390–406. DOI: 10.1016/j.commatsci.2011.10.017.

The AI-TranspWood project, HORIZON-CL4–2023-RESILIENCE- 01–23 (Grant Agreement 101138191), is gratefully acknowledged. This project is co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them.

Constitutive Models for 2D Nanomaterials Subjected to Biaxial Loading

Shahbaz Paramban[a], John Sellinger[b†], Parker Cain[a†], Jesse Hackmann[a†] & Hessam Yazdani[a]

[a] Department of Civil and Environmental Engineering, University of Missouri, Columbia, MO, USA
[b] Department of Chemical and Biomedical Engineering, University of Missouri, Columbia, MO, USA
[†] These authors contributed equally to this work.

E-mail: hyazdai@missouri.edu

Abstract

Recent developments in flexible electronics and wearable systems require predictive constitutive descriptions of damage initiation and fracture in two-dimensional (2D) materials subjected to multiaxial loading. Uniaxial strength metrics are insufficient for reliability assessment because service conditions impose concurrent orthogonal strains that modify crack nucleation thresholds and fracture pathways. This study uses molecular dynamics simulations to develop constitutive failure criteria for biaxial tension in three 2D materials: graphene, hexagonal boron nitride (h-BN), and C3N. Biaxial loading is imposed over prescribed stress/strain ratios and temperatures, and rupture is identified through the transition from progressive bond-length elongation to lattice instability. Atomic virial stresses are evaluated to construct failure loci in the space of in-plane principal stresses. For each material, stresses along the dominant lattice directions are normalized by the corresponding uniaxial ultimate strengths at a given temperature to define dimensionless stress states. The resulting rupture states define limiting stress-ratio surfaces that serve as constitutive strength envelopes for multiaxial loading. Each envelope is represented using a low-parameter bilinear criterion, and a circular closed-form approximation is provided for efficient implementation in continuum damage and fracture formulations. The proposed constitutive envelopes provide compact inputs for damage evolution and fracture initiation modeling of 2D materials under biaxial tension, supporting computationally efficient failure prediction within continuum, cohesive, and reduced-order frameworks.

Keywords: Constitutive modeling, Failure envelope, Biaxial tension, Molecular dynamics

References:

[1] H. Yazdani, K. Hatami, Failure Criterion for Graphene in Biaxial Loading—A Molecular Dynamics Study, Modell. Simul. Mater. Sci. Eng. 23 (2015) 065004.

[2] H. Ghasemi, J.E. Rutledge, H. Yazdani, Mechanical Properties of Defective Cyanoethynyl (2D Polyaniline–C3N): A Comparative Molecular Dynamics Study versus Graphene and Hexagonal Boron Nitride, Physica E: Low-dimensional Syst. Nanostruct. 121 (2020) 114085.

Numerically Supported Development for Concrete Shear Fatigue Testing under Varying Normal Actions

Carlos Arboleda, Mario Aguilar, Alexander Scholzen & Rostislav Chudoba

Center for Structural Concrete Physics, RWTH Aachen University, Aachen, Germany

E-mail: carboleda@imb.rwth-aachen.de

Abstract

The multi-axial fatigue behavior of concrete under combined shear and normal stresses governs the performance of critical infrastructure systems such as wind turbine towers and bridges. Despite its practical relevance, experimental methodologies capable of systematically investigating shear fatigue under controlled normal stress conditions remain limited. Recent research highlights the need for test frameworks that explicitly address different stress configurations and associated fatigue process zones [1]. This study presents an integrated experimental–computational framework for investigating concrete shear fatigue under varying normal actions. The approach is based on systematic variation of the ligament orientation in the Punch-Through Shear Test (PTST), enabling controlled generation of stress states ranging from shear combined with compressive normal stress to near-simple shear and shear with tensile normal stress. Finite element analyses are employed to optimize specimen geometry, ensuring localized deformation, uniform stress distributions within the ligament, and minimized boundary effects, thereby reducing scatter and enhancing reproducibility. In parallel, the thermodynamically based microplane fatigue model MS1 is used to analyze stress redistribution, anisotropic damage evolution, and energy dissipation mechanisms associated with cumulative inelastic shear strain and inter-aggregate sliding at subcritical loads [2]. Preliminary results indicate distinct fatigue damage evolution patterns across different normal–shear combinations, demonstrating that geometry-induced stress states significantly influence multi-axial fatigue behavior. The proposed framework provides a systematic basis for studying coupled shear–normal fatigue and supports the advancement of physically based constitutive models for structural design under complex cyclic loading.

Keywords: Concrete Fatigue, Shear Fatigue, Multi-axial Loading, Punch-Through Shear Test, Microplane Model

References:

[1] A. Baktheer, C. Goralski, J. Hegger, R. Chudoba, Stress configuration-based classification of current research on fatigue of reinforced and prestressed concrete, Structural Concrete 25(3) (2024) 1765–1781.

[2] M. Aguilar, A. Baktheer, R. Chudoba, Multi-axial fatigue of high-strength concrete: Model-enabled interpretation of punch-through shear test response, Engineering Fracture Mechanics 311 (2024) 110532.

Modified non-local damage model: Resolving spurious damage evolution

Roshan Philip Saji[1], Panos Pantidis[1], Mostafa E. Mobasher[1]

[1]Civil and Urban Engineering Department, New York University Abu Dhabi, Abu Dhabi, P.O. Box 129188, UAE

Abstract

We present a modified non-local gradient damage (MNLD) model that addresses the pathological damage widening phenomenon observed in gradient-enhanced continuum damage models. Reliable modeling of damage initiation and crack growth is essential for structural safety and lifecycle management, yet current numerical approaches remain inadequate. Discrete fracture and phase-field formulations, while physically realistic, are computationally expensive for practical large-scale problems and show limited generalizability across material classes. By contrast, classical phenomenological gradient damage frameworks are computational efficient but exhibit nonphysical widening of the damage zone. Our study addresses the challenges of conventional gradient damage formulations by modifying both the stress degradation function and the forcing term in the Helmholtz free energy expression. With these changes, the thermodynamic damage driving force vanishes and evolution of the forcing term progressively diminishes as damage reaches its terminal value. As a result, the damage localization zone maintains a constant fixed-width during its evolution. The development of the MNLD model is informed by two intermediate formulations, each targeting one of these modifications independently before being combined into a unified formulation. The numerical validation of the MNLD model is conducted through a series of 1D, 2D and 3D benchmark simulations, which demonstrate its ability to consistently yield fixed-width damage bands. Importantly, the MNLD model can be easily incorporated into existing finite element implementations of gradient damage models with only minor modifications. Overall, our findings demonstrate a practical and rigorous resolution to the long-standing issue of artificial damage band broadening in gradient-enhanced damage approaches, offering an effective and practical solution for engineering applications.

Keywords:

Gradient, Non-local, Damage, Thermodynamic, Phase-field

Reference:

[1] Saji, R. P., Pantidis, P., & Mobasher, M. E. (2025). Modified non-local damage model: resolving spurious damage evolution. *Engineering Fracture Mechanics*, 111767.

Comparison of Begley–Landes (1972) and ASTM D8044 Multiple Specimen Methods for Determining the Critical J-Integral of Asphalt Concrete

Abhilash Vyas [a] **& Ramez Hajj** [a]

[a] Civil and Environmental Engineering, Grainger College of Engineering, University of Illinois at Urbana-Champaign, Urbana, IL, USA 61801

E-mail: rhajj@illinois.edu

Since its introduction by Rice [1] in 1967, the J-integral (J) has been widely used as a fracture criterion. Owing to its path independence, J uniquely characterizes the near-tip stress and strain fields and has therefore been widely accepted as a material property with limited sensitivity to specimen size effects. Although originally formulated for linear elastic materials, Rice extended the concept to nonlinear materials and showed J represents the energy release rate and can be evaluated from global load–displacement response without explicit knowledge of crack-tip fields. Begley and Landes [2] later introduced an experimental procedure for evaluating J, commonly referred to as the multiple specimen method. This approach determines J by quantifying differences in the energy absorbed by specimens with neighboring crack sizes. While accurate, the method requires testing several specimens with different notch depths and involves relatively cumbersome data reduction procedures, which led to development of single specimen method to compute J. Despite these developments, fundamental fracture mechanics approaches have seen limited application in Asphalt Concrete (AC), where most state agencies rely on empirical or semi- empirical indices to evaluate cracking potential. AC is a heterogeneous, viscoelastic particulate composite, which further complicates its fracture characterization. Researchers in Louisiana [3] adopted a modified version of Begley and Landes formulation to compute the critical J-integral (J_c), later standardized as ASTM D8044. Although widely used, this method employs simplified analysis that deviates from the original formulation. This study compares the Begley and Landes multiple specimen procedure with ASTM D8044 for determining J_c using semi-circular bend specimens, focusing on differences in experimental requirements, data reduction procedures, and resulting fracture parameters. In addition, J_c is evaluated by assuming different crack initiation criteria identified using load–displacement response, and Digital Image Correlation (DIC), and the most appropriate criterion is identified for routine testing.

Keywords: asphalt concrete, fracture, J-integral, semi-circular bend

References:

[1] James R Rice, A path independent integral and the approximate analysis of strain concentration by notches and cracks, Technical report, 1968.

[2] JA Begley, JD Landes, The J integral as a fracture criterion, 1972.

[3] LN Mohammad, Z Wu, and MA Aglan, Characterization of fracture and fatigue resistance on recycled polymer-modified asphalt pavements, In Proc., RILEM: 5th Int. Conf. on Cracking in Pavements Mitigation, pages 375–382, 2004.

A Data-driven multiscale Lattice Discrete Particle Model (LDPM) for digital twin modeling of concrete structures

Baixi Chen[1], Alessandro Fascetti[1]

[1]Department of Civil, Environmental and Construction Engineering, University of Central Florida, Orlando FL, 32816 USA

Abstract

Degradation, damage, and failure mechanics in cementitious composites exhibit significant variability at the macroscopic scale, which is predominantly driven by stochasticity at the spatial scale of the coarse aggregate particles, referred to in this context as mesoscopic scale. However, mesoscale material parameters are difficult to estimate, making uncertainty quantification a fundamental scientific and engineering challenge. To address this limitation, a data-driven multiscale inverse inference framework is proposed to quantify the stochastic mesoscale behavior by integrating both mesoscale and macroscale observations. In this framework, a stochastic data-driven model using a hybrid Proper Orthogonal Decomposition–Gaussian Process Regression (POD-GPR) algorithm is first developed based on data generated by mesoscale Lattice Discrete Particle Model (LDPM) simulations. Leveraging this efficient data-driven model, a novel multiscale Bayesian inverse inference method is proposed to infer the stochastic distributions of the mesoscale features. When applied to experimental data, the proposed framework successfully captures the stochastic distributions of mesoscale material parameters, reproduces macroscale responses, and outperforms conventional single-scale Bayesian inference approaches. Additionally, SHapley Additive exPlanations (SHAP) are integrated to further interpret the effect of mesoscale stochastic material behavior on macroscale uncertainty, offering valuable insights for the accuracy improvement of LDPM simulations and future mesoscale-level optimization to achieve more robust macroscale performance.

Variance propagation in a mesoscale discrete model of concrete fatigue

Miroslav Vořechovský [a] **& Adam Sklenář** [a]

[a] Institute of Structural Mechanics, Brno University of Technology, Brno, Czechia, Europe

E-mail: *miroslav.vorechovsky@vut.cz*

Abstract

Concrete exhibits pronounced heterogeneity at the mesoscale, which significantly influences its strength and fatigue performance. Discrete models that explicitly represent the material structure provide a promising framework for capturing these effects. In this contribution, we employ a particle-based mesoscale discrete model in which individual aggregates are connected by mechanical links governed by a vectorial interface constitutive law combining damage and plasticity. The model represents the interactions between adjacent mineral grains and naturally captures stress redistribution and crack evolution in heterogeneous concrete. Similar modeling concepts have previously demonstrated the ability to reproduce monotonic, cyclic, and fatigue responses of concrete specimens. The present study focuses on the propagation of variance from uncertain model parameters to structural responses. A large ensemble of numerical simulations of concrete specimens subjected to monotonic compression and fatigue loading is generated by systematically varying selected mesoscale parameters. The resulting dataset allows us to investigate the sensitivity of key macroscopic responses, including compressive strength and the number of cycles to failure under different stress ranges. The analysis reveals that monotonic compressive strength and fatigue lifetime are controlled by different subsets of model parameters, indicating distinct correlations between input parameters and output responses for monotonic and cyclic loading. Furthermore, the classical Palmgren–Miner rule is examined within the mesoscale framework and employed to assess residual load-bearing capacity under variable-amplitude loading, including sequence effects. The results demonstrate how mesoscale stochastic simulations can provide insight into uncertainty propagation and fatigue reliability of concrete structures.

Keywords: concrete fatigue, mesoscale discrete model, variance propagation, uncertainty analysis

References:

[1] M. Vořechovský, M., V. Sadílek, J. Eliáš, J. Květoň, & J. Mašek. Mesoscale discrete modeling of fatigue in concrete. under preparation (2026)

[2] R. Chudoba, M. Vořechovský, M. Aguilar, A. Baktheer, Coupled sliding–decohesion–compression model for a consistent description of monotonic and fatigue behavior of material interfaces, Comput. Methods Appl. Mech. Eng. 398 (2022) 115259.

Comparative Analysis of Crack Driving Force for Quasi-Brittle Material Using Phase Field Model

Naqibullah Mehri [a], **Hemam Amarjit Singh**[a], **Rimen Jamatia** [a] **& Surendra Beniwal** [a]

[a] Indian Institute of Technology Jammu, Department of Civil Engineering, Jammu, India

E-mail: *2023RCE2042@iitjammu.ac.in*

Abstract

The phase-field approach has become a widely used computational framework for modelling fracture in quasi-brittle materials such as concrete. Within this formulation, the representation of the crack driving force is of fundamental importance, as it governs crack initiation, propagation, and the resulting mechanical response of the material. A suitable definition of the crack driving force is therefore necessary to capture different fracture modes and to obtain physically meaningful crack evolution under complex loading conditions.

In the present study, a phase-field model formulation is implemented in ABAQUS through a user-defined UMAT/VUMAT subroutine to simulate fracture processes in quasi-brittle materials. The capability of the numerical framework is evaluated using a series of well-known two-dimensional and three-dimensional benchmark problems reported in the literature. These examples include Mode-I tensile fracture, Mode-II shear fracture, Mode-III torsional fracture, and mixed-mode fracture. In addition, the influence of different crack driving force formulations on the predicted fracture behaviour is examined and compared. The numerical results indicate that the choice of crack driving force has a significant impact on crack patterns, load–displacement responses, and the overall failure mechanisms obtained from phase-field simulations.

Keywords: Phase-field model, crack driving force, ABAQUS UMAT/VUMAT

References:

[1] J. Y. Wu and Y. Huang, “Comprehensive Implementations of Phase-Field Damage Models in Abaqus,” Theoretical and Applied Fracture Mechanics, vol. 106, pp. 102440, 2020.

[2] Y. Navidtehrani, C. Betegón and E. Martínez-Pañeda, “A Simple and Robust Abaqus Implementation of the Phase Field Fracture Method,” Applied Engineering Science, 2021.

[3] X. Ge, L. Zhou, S. Bagherifard and M. Guagliano, “A Simple and Efficient Implementation of Explicit Phase Field Method in ABAQUS to Address Complex Three-Dimensional Fracture Problems,” Engineering Fracture Mechanics, vol. 323, pp. 111222, 2025.

Monolithic, Partially Staggered, and Fully Staggered Schemes for Thermomechanically Coupled Phase-Field Fracture Simulations

Lampros Svolos [a], **Tao Jin** [b]

[a] Department of Civil and Environmental Engineering, University of Vermont, Burlington, VT, USA
[b] Department of Mechanical Engineering, University of Ottawa, Ottawa, Ontario, Canada

E-mail: *Lampros.Svolos@uvm.edu*

Abstract

In coupled thermomechanical problems, crack propagation is driven not only by mechanical loading but also by thermal effects. Although phase-field fracture models have gained significant attention due to their ability to capture complex crack topologies, an additional partial differential equation (the phase-field equation) is introduced into the mathematical formulation. Thermomechanically coupled fracture simulations typically require solving a system of three governing equations: the mechanical equilibrium equations, the heat equation, and the phase- field evolution equation. Solution strategies for these coupled problems can generally be classified into three categories: monolithic schemes, fully staggered schemes, and partially staggered (hybrid) schemes. In monolithic schemes, the unknown fields (displacement, temperature, and the phase field) are combined into a single solution vector and solved simultaneously. Fully staggered schemes treat each field separately by partitioning the coupled thermomechanical fracture problem into three sub-problems: the mechanical sub-problem, the thermal sub-problem, and the fracture sub- problem. Finally, partially staggered schemes hybridize these approaches by grouping certain fields together and coupling the resulting sub-problems sequentially. In this talk, we present a highly efficient monolithic scheme for modeling fracture in coupled thermomechanical problems. The proposed approach leverages the limited-memory BFGS (L-BFGS) method, along with an adaptive mesh refinement (AMR) strategy based on the element- wise L^2-projection of the history variable to enforce crack irreversibility while improving efficiency. Under the same computational setup, the performance of the proposed monolithic scheme is compared with two alternatives: the fully staggered scheme and a partially staggered scheme in which the problem is divided into two sub-problems: a thermomechanical sub- problem and a phase-field sub-problem. We also investigate the impact of different direct and iterative linear solvers on the overall numerical performance of these schemes. The developed monolithic scheme provides an efficient framework that may serve as a universal strategy for solving other types of multiphysics phase-field fracture problems.

Keywords: phase-field fracture, thermomechanical coupling, monolithic and staggered schemes

Total Lagrangian Material Point Method for dynamic ductile fracture

Borys Zyto [a], Lampros Svolos [b] & Emmanouil Kakouris [a]

[a] School of Engineering, University of Warwick, Coventry, the United Kingdom
[b] Department of Civil and Environmental Engineering, University of Vermont, Burlington, VT, USA
E-mail: borys.zyto@warwick.ac.uk

Abstract

Understanding the interplay between thermo-mechanics and damage remains an open problem within the computational mechanics community. In dynamically loaded metallic materials, mechanical energy coming from plastic deformations may be converted to heat. Temperature rises result in thermal softening, causing the localization of plastic deformations and triggering shear banding. Simultaneously, large plastic deformations act as a precursor to ductile failure. The interactions between these mechanisms lead to a complex, coupled multi-field system requiring a robust computational framework for accurate prediction of material response. Crack propagation problems have been traditionally solved utilizing finite element based methods. However, in problems involving large elastoplastic flow, conventional approaches may struggle due to mesh-related numerical artifacts. In order to address that, this study utilizes the Total Lagrangian Material Point Method (TLMPM), a hybrid particle based method aimed at solving large deformation solid mechanics problems [2]. We integrate a thermodynamically consistent, variational phase-field ductile fracture model into a state-of-the-art TLMPM framework to simulate crack propagation across varying loading and thermal regimes. The proposed finite strain, elasto-viscoplastic framework is capable of capturing localized plastic effects and predicting complex crack paths, while remaining numerically stable. The performance of the proposed framework is examined in a series of numerical examples and compared against benchmarks presented in the literature.

Keywords: Ductile Fracture, Heat Transfer, Material Point Method

References:

[1] L. Svolos et al., A phase-field fracture formulation for generalized standard materials: The interplay between thermomechanics and damage, Journal of the Mechanics and Physics of Solids, 201,2025.

[2] E. G. Kakouris, S. P. Triantafyllou, Phase-Field Material Point Method for dynamic brittle fracture with isotropic and anisotropic surface energy, Computer Methods in Applied Mechanics and Engineering, 357, 2019.

A Two-scale Framework for Multiscale Phase Field Fracture

Yangzi He [a] **& Shabnam J. Semnani** [a]

[a] Department of Structural Engineering, University of California San Diego, La Jolla, USA

E-mail: ssemnani@ucsd.edu

Abstract

The phase field approach has been extensively developed and applied in single-scale fracture analysis, primarily due to its ability to model strong discontinuities through topological approximations, as well as its advantages in continuous failure process modeling. However, the application of the phase field method to multiscale fracture analysis remains relatively unexplored. Many existing studies in this area fail to effectively distinguish between the multiple resolutions of continua, especially when dealing with composite materials. These studies typically rely on single-scale analysis enhanced by local refinement, high-order interpolation, or homogenized shape functions, which only approximate lower-dimensional behaviors rather than fully capturing the interaction of multiple different scales. This work proposes a novel two-scale phase field fracture analysis framework which integrates computational homogenization to model both the macroscopic stress and the state of damage, as well as the localized fracture behavior within representative volume elements (RVE). This simulation method enables a deeper understanding of the initiation and propagation of microcracks in composite materials, providing valuable insights into material behavior at different scales. Additionally, the proposed method has been implemented for single-scale, RVE, and two-scale problems, validating its effectiveness across varying levels of analysis.

Keywords: Phase field, fracture mechanics, multiscale, composites

MS2

Digital Twin–Enabled Automation of Marshalling Yards for Adaptive and Efficient Single Wagonload Services

Boban Djordjevic [a], **Evelin Krmac [b]**

a Senior Researcher (Division of Transport Planning, KTH Royal Institute of Technology, Stockholm, Sweden)

b Associate Professor (Faculty of Maritime Studies and Transport, University of Ljubljana, Portorož, Slovenia)

E-mail: boband@kth.se

Abstract

Rail freight continues to lose market share to road transport due to limited flexibility, interoperability challenges, service disruptions, and declining volumes across most EU countries [1]. Single wagonload (SWL) services provide a flexible alternative for smaller shipments, but their performance depends heavily on the efficiency of marshalling yards as core production nodes. Manual operations, unplanned train movements, and timetable deviations often create bottlenecks that spread across the wider rail network, reducing service reliability and customer satisfaction [2]. This study proposes a Digital Twin (DT) framework to enable greater automation and digitalisation in marshalling yards. Building on recently defined Grades of Automation for Shunting Operations [3], the research develops a multi-agent simulation-based DT model that represents yard components, operational processes, and their interaction with network management systems. The model is implemented in the AnyLogic platform and validated through a case study of Hallsberg marshalling yard, one of the largest freight yards in Scandinavia. Each infrastructure element, train, and wagon is modelled as an intelligent agent, enabling real-time monitoring, simulation, and scenario-based performance assessment. Results show that integrating yard automation with real-time network management improves departure stability, increases throughput, and reduces operational conflicts under varying traffic conditions. The proposed DT offers a scalable architecture that supports progressive automation while maintaining cost-effectiveness. This study presents the first multi-agent Digital Twin model for marshalling yard automation, providing a practical pathway towards adaptive, resilient, and customer-oriented rail freight operations.

Keywords: Digital Twin, marshalling yard automation, single wagonload, multi-agent simulation

References:

[1] Potter, A., Soroka, A., & Naim, M. (2022). *Regional resilience for rail freight transport.* Journal of Transport Geography, 104, 103448. https://doi.org/10.1016/j.jtrangeo.2022.103448

[2] Guglielminetti, P., Piccioni, C., Fusco, G., Licciardello, R., & Musso, A. (2018). *Rail freight network in Europe: Opportunities provided by re-launching the single wagonload system.* Transportation Research Procedia, 25, 5185–5204. https://doi.org/10.1016/j.trpro.2018.02.047

[3] Automated Rail Cargo Consortium (ARCC), REAL-TIME YARD MANAGEMENT – D2.2 Description of Business Processes of a Network Management System and the Interactions/Interfaces with a Real-time Yard Management System, Project Deliverable D2.2, 202X.

A State-of-the-Art Finite Element Model for Train Derailments

Steven W. Kirkpatrick [a], Paul Gharzouzi [b], Chen-Yu Lin [c], Christopher P.L. Barkan [d], Paolo Gardoni [d]

Applied Research Associates, Inc. Los Altos, California
Department of Civil and Environmental Engineering American University of Beirut, Beirut, Lebanon University of Illinois Urbana-Champaign, Urbana, Illinois
Department of Transportation and Logistics Management National Yang Ming Chiao Tung University, Hsinchu City, Taiwan
Department of Civil and Environmental Engineering University of Illinois Urbana-Champaign, Urbana, Illinois

Abstract

Understanding the dynamic and structural behavior of trains during a derailment is critical for enhancing railway safety and minimizing the consequences of derailments. Derailment simulation models, also known as physical models, are a valuable approach to enhance this understanding by simulating the behavior of a derailed train and its railcars. This paper first provides a critical review of physical models of train derailments, categorized into multi-body simulation (MBS) and finite element (FE) models. It also covers the applicability of the MBS and FE models to different aspects of the derailment phenomenon, including the motion of derailed railcars, in-line train kinematics, railcar structural deformation, and derailment-caused impact forces. For each model category, the review also discusses the advantages, contributions, and limitations. Following the review, the paper presents a state-of-the-art FE train derailment model. This detailed three-dimensional (3D) model incorporates a variety of accident and train characteristics and includes sub-models of various train and site features to accurately simulate the derailment event. Three simulations of real-world derailment events are presented to showcase the model's ability to replicate the post-derailment behavior of a train.

Keywords: Train Derailment Simulation, Multi-Body Simulation, Finite Element Model, Derailment Kinematics, Impact Forces

Techno-economic feasibility study of district-integrated rooftop urban ice rink: Computational Modeling of District Energy Integration

Reza Chehrazi [a], Jan-Olof Dalenbäck [b], Seidpooyan Ghafoori [c], Anders Strand [d]

[a] Chalmers University of Technology, Space, Earth & Environment, Gothenburg, Sweden

[b] Chalmers University of Technology, Artiticture & Civil Eng, Gothenburg, Sweden

[c] Design and Media Technology, Aalborg, Denmark

[d] Gothenburg Energy AB, Energy efficiency Department, Gothenburg, Sweden

Abstract

The sustainability of urban recreational infrastructure depends on balancing advanced thermodynamic performance with robust economic viability. This study presents a multi-physics, techno-economic analysis of a proposed 1,100 m² open-roof ice rink at Rosenlundsverket in Gothenburg, Sweden, assessing seven energy system configuration scenarios over a 25-year life-cycle cost (LCC) horizon. Using a transcritical CO_2 (R744) refrigeration cycle as the reference, the analysis applies a 4% discount rate to identify optimal integration pathways with district heating and cooling networks and advanced hybrid configurations, supporting Gothenburg's 2030 sustainable urban development agenda. The methodology couples detailed SMHI meteorological datasets with thermodynamic simulations, validated using Danfoss Coolselector® 2 and EBSILON® Professional. Heat absorption from the ice pad is dimensioned through an integrated model subject to open-roof climatic variables (solar gains, wind convection) and a validated operational load profile based on empirical correlations from Salib (2021) and ASHRAE standards, adjusted for open-roof conditions following Karampour (2011). CO_2 system performance factors are derived from Scandinavian case studies, while dynamic loads incorporate solar radiation, wind-driven convection, and precipitation at a 20 m elevation. Results show pronounced techno-economic differences among configurations. The hybrid "COMBO" scenario, featuring ammonia–water absorption chillers with waste heat recovery, achieves the largest energy savings, reducing annual electricity use to 643,627 kWh/year (37% lower than the reference 1,023,249 kWh/year). However, LCC analysis indicates that all advanced configurations yield negative net present values (NPV) over 25 years, with the reference at -440.7 million SEK and the COMBO with heat recovery at -433.5 million SEK. The River Cooling System offers thestrongest financial performance, with an NPV of -432.9 million SEK (7.8 million SEK improvement over the reference) and lower capital investment (14.1 million SEK vs. 13.0 million SEK for the reference). The Cascade to District Cooling configuration provides the best overall balance between energy efficiency and financial viability, achieving an NPV of -432.3 million SEK (8.4 million SEK improvement) and a 9.1% reduction in electricity consumption to 930,226 kWh/year. The Combined District Heating integration yields an 8.8% electrical efficiency gain, with thermal recovery delivering an additional 30% system benefit. Although the COMBO scenarios require higher capital investments (20.6–21.7 million SEK), they deliver the highest seasonal performance factors (SPF 4.51–6.08 versus 2.72 for conventional designs) and substantial waste heat recovery potential (up to 1,507 MWh/year) that can be monetized through district heating grid integration at 0.10–0.53 SEK/kWh. Overall, the optimized configurations achieve 56–63% of the Swedish national average energy consumption benchmark for ice rinks, demonstrating the technical feasibility of low-carbon urban recreational infrastructure through strategic district energy integration.

Keywords: Techno-economic optimization, District energy integration, Ice rink energy systems, Waste heat recovery, CO_2 refrigeration (R744)

Experimental and Numerical Investigation of Flow Separation Phenomena in Dual-Supersonic Nozzles under Over-Expanded Operating Conditions

HAMAIDIA Walid [a], YAHIAOUI Toufik [b], BENDINE Kouider [c], HIBER Houssam Eddine Nadir [c]

[a] High School of Aeronautical Techniques, Dar elbeida, Algiers, Algeria

[b] Institute of Aeronautics and Space Studies, University of Blida-1, Algeria

[c] Djillali Liabes University of Sidi Bel Abbes, Algeria

E-mail: walidhamaidia84@gmail.com

Abstract

This paper presents an experimental and numerical investigation of flow separation phenomena and shock-wave/boundary-layer interactions in a newly developed Dual Supersonic Nozzle (DSN) operating under over-expanded conditions associated with altitude variations and changes in the Nozzle Pressure Ratio (NPR). Experimental measurements were conducted using a dedicated supersonic nozzle test facility to determine wall-pressure distributions over a wide range of NPR conditions. The experimental database was complemented by detailed Computational Fluid Dynamics (CFD) simulations employing four widely used turbulence models, namely the k–ω SST, Spalart–Allmaras, and Menter SST models. In addition, the study incorporates the assessment of an analytical engineering approach together with a semi-empirical Shock Wave/Boundary Layer Interaction (SWBLI) criterion commonly adopted for predicting flow separation in over-expanded nozzles. The numerical predictions exhibited strong agreement with the experimental pressure distributions, demonstrating the capability of the adopted computational methodology to accurately capture the complex internal flow structures associated with over-expanded supersonic regimes. The computational domain was discretized using structured grids, and grid-independence was verified through three mesh resolutions. The aerodynamic performance of the proposed DSN configuration was compared with two conventional nozzle geometries, namely the Minimum Length Nozzle (MLN) and the Dual Expansion Nozzle (DEN). Results indicate that increasing NPR under strongly over-expanded conditions promotes flow separation and generates significant lateral loads in all nozzle configurations. However, the DSN exhibited lower side-load intensity and delayed flow separation occurring closer to the nozzle exit. This behavior contributes to reduced boundary-layer losses, limited exit Mach number degradation, and improved thrust performance compared with conventional nozzle designs.

Keywords: Dual Supersonic Nozzle (DSN), Over-Expanded Flow, Shock Wave/Boundary Layer Interaction (SWBLI), Computational Fluid Dynamics (CFD), Side Loads, Nozzle Pressure Ratio (NPR).

References:

[1] Chahat T., H. Kebab. W. Hamaidia, B Benaouda Zouaoui. ''Analysis of Dual bell nozzle configuration''. Journal of applied fluid mechanics 18 (7) 1767-1781. (2025).

[2] Hamaidia W., Yahiaoui T, and Sellam M, "CFD investigation for supersonic two parallel expansion nozzles," Advances in Space Research, Vol. 75, N° 02, PP. 2378-2390, (2025).

[3] Hamaidia W., Zebbiche T., Sellam M., and Allali A., "Performances improvement of the supersonic nozzles design using a high-temperature model," In: Proceedings of the Institute of Mechanical Engineering, Part G: Journal of Aerospace Engineering, Vol 233, N° 13, PP. 4895-4910, (2019).

MS3

Seismic Resilience Assessment of Piles Subjected to Liquefaction-Induced Lateral Spreading

Hessam Yazdani[a], **Davide Forcellini**[b], **Faramarz Ranjbar**[c], **Ali Asgari**[c] **& Mohsen Bagheri**[d]

[a] Department of Civil and Environmental Engineering, University of Missouri, Columbia, MO, USA
[b] Faculty of Civil Engineering, University of San Marino, Serravalle, San Marino
[c] Department of Civil Engineering, University of Mazandaran, Babolsar, Iran
[d] Department of Civil Engineering, Babol Noshirvani University of Technology, Babol, Iran

E-mail: *hyazdai@missouri.edu*

Abstract

The seismic resilience of deep foundations subjected to liquefaction-induced lateral spreading has remained largely unexplored. Using 3D nonlinear dynamic finite-element analyses, this study quantifies the displacement-based seismic resilience of capped, rock-socketed single piles in liquefiable, gently sloping ground and develops a configuration-to-recovery mapping that links site and structural parameters to post-earthquake rapidity. Models vary systematically in ground inclination (0–6°), liquefiable layer thickness (5–15 m), and axial load ratio (0.10, 0.25, 0.50, and 0.75 of ultimate axial capacity) to quantify both transient response and recovery implications. Beyond peak demands, the analysis tracks the spatiotemporal evolution of excess porewater pressure during shaking and the evolution of lateral soil pressures during and after liquefaction, including the re-equilibration phase once liquefaction completes. Results show that resilience outcomes are governed by an interaction among slope-driven kinematics, the thickness- controlled extent of strength loss and lateral spreading, and axial-load–dependent amplification of pile–cap displacement demand. These coupled effects manifest in distinct time histories of pore-pressure buildup and dissipation and corresponding shifts in lateral pressure distribution that control pile demand evolution. The resilience framework provides a practical mapping from configuration to rapidity, enabling rapid screening of recovery expectations for deep foundations in laterally spreading ground.

Keywords: Seismic resilience, liquefaction-induced lateral spreading, pile demand and time history

References:

[1] A. Asgari, F. Ranjbar, M. Bagheri, Seismic Resilience of Pile Groups to Lateral Spreading in Liquefiable Soils: 3D Parallel Finite Element Modeling, Structures (2025) 108578.

[2] D. Forcellini, An Expeditious Framework for Assessing the Seismic Resilience (SR) of Structural Configurations, Structures 56 (2023) 105015.

[3] D. Forcellini, K.N. Kalfas, A Framework to Quantify the Impact of Deterioration on the Seismic Resilience of Structures, Struct. Infrastruct. Eng. (2025) 1–9.

UHPC for Advancing Structural Resilience of Buildings, Bridges, and Nuclear Infrastructure

Mohamed A. Moustafa [a]

[a] Associate Professor of Civil and Urban Engineering (New York University Abu Dhabi, Abu Dhabi, UAE)

E-mail: *mohamed.moustafa@nyu.edu*

Abstract

Ultra-high performance concrete (UHPC) has emerged as a transformative material capable of significantly enhancing structural resilience under extreme loading conditions across diverse infrastructure systems. Over the past decade, we have conducted various analytical, numerical, and experimental investigations to quantify the role of UHPC in rethinking the structural design and improving performance of buildings, bridges, and nuclear structures under extreme events like seismic, impact, and thermal accident loading scenarios. Compared to conventional normal-strength concrete (NSC), UHPC exhibits superior compressive and tensile strength, enhanced tensile ductility, reduced permeability, and improved durability, fundamentally altering structural response under extreme hazards. Experimental and analytical studies on UHPC bridge columns and connections have demonstrated improved energy dissipation, delayed damage initiation, and enhanced confinement efficiency relative to NSC systems [1]. Additional investigations and full-scale testing on slender UHPC columns of high-rise buildings have shown improved stability performance and refined buckling resistance characteristics, supporting the development of new design provisions and performance-based design approaches for resilient bridge and building applications [2]. In nuclear infrastructure, nonlinear thermal–structural analyses incorporating advanced damage-plasticity constitutive modeling have demonstrated that UHPC significantly reduces damage-prone regions and inelastic strain demands in spent fuel storage structures subjected to accident-level thermal loading [3]. Collectively, these findings indicate that UHPC not only increases baseline strength but also enhances robustness, redundancy, and post-event functionality, key attributes of structural resilience. This presentation synthesizes these various investigations to illustrate how strategic implementation of UHPC—either as a full replacement or targeted material upgrade in critical regions—can advance the resilience of next-generation infrastructure systems under extreme events.

Keywords: UHPC, structural resilience, seismic performance, bridges, thermal accidents, nuclear structures.

References:

[1] Aboukifa, M., and Moustafa, M.A. (2021). Seismic performance of UHPC bridge columns with high-strength reinforcement. Engineering Structures.

[2] Aboukifa, M., and Moustafa, M.A. (2019). Behavior and stability of slender UHPC columns reinforced with high-strength steel. CRC Press.

[3] Igrashkina, N., Moustafa, M.A., and Hadj-Nacer, M. (2025). Comparison of thermal and structural performance of conventional concrete and UHPC for spent nuclear fuel storage structures. Nuclear Engineering and Design.

Characterization Testing of Friction Pendulum Bearings with Advanced Axial Force Control

Yunbyeong Chae [a], **Chunghyun Lee** [a]

[a] Department of Civil, Urban, and Environmental Engineering, Seoul National University, Seoul, South Korea

E-mail: *ybchae@snu.ac.kr*

Abstract

Friction pendulum (FP) bearings are widely adopted base isolation devices due to their effective energy dissipation and inherent self-centering capability. Their dynamic behavior is governed by frictional energy dissipation and gravity-induced restoring forces, both of which are strongly dependent on the axial force from the superstructure. The friction coefficient of an FP bearing varies significantly with the applied axial load; therefore, accurate maintenance of the target axial force is essential during characterization testing. However, the vertical motion induced by lateral sliding along the concave surface of FP bearings makes reliable axial force control challenging, especially when conventional PID controllers are employed. To accurately characterize the lateral behavior of FP bearings under varying axial loads, this study implements a displacement-based adaptive time series (D-ATS) force control algorithm[1] in conjunction with a specially designed flexible loading frame (FLF). The axial force control performance of the proposed approach is systematically compared with that of a conventional PID controller under various axial force and lateral displacement protocols. Experimental results demonstrate that, under PID control, axial force errors are pronounced and exhibit significant fluctuations. In contrast, the proposed method achieves stable and accurate axial force regulation throughout the tests. The comparative performance of the axial force control strategies and their influence on the lateral response of the FP bearing are presented and discussed in detail.

Keywords: seismic isolation, friction pendulum bearing, axial force control, flexible loading frame

References:

[1] Y. Chae, R. Rabiee, A. Dursun, and C-Y. Kim, Real-Time Force Control for Servo-Hydraulic Actuator Systems Using Adaptive Time Series Compensator and Compliance Springs, Earthquake Engineering & Structural Dynamics. 47 (2018) 854-871.

Wind-Induced Torsional Loads on Irregular Low-Rise Buildings

Mahmoud Abdallah [a], Omar Abdallah [a], Rani Alsayegh [a], Ioannis Zisis [b]

[a] Ph.D. Student, Department of Civil and Environmental Engineering, Florida International University, Miami, FL, USA

[b] Professor, Department of Civil and Environmental Engineering, Florida International University, Miami, FL, USA

E-mail: izisis@fiu.edu

Abstract

Irregular plan geometry can produce torsional loading in low-rise buildings that is not represented adequately by rectangular-plan assumptions used in current MWFRS evaluation [1,2]. This study examines directional base shear and torsional moment in irregular low-rise buildings using synchronous wall-pressure measurements from rigid models tested at the NHERI Wall of Wind Experimental Facility. The model set includes multiple plan shapes and roof types. Global base shears and torsional moments are obtained by tributary-area integration of wall pressures, and directional peak response is evaluated relative to rectangular reference cases. The broader model set allows the effects of plan shape and roof form on torsional response to be compared on a consistent basis.

Results indicate that torsional response is governed primarily by plan irregularity, while roof type further modifies both torsional magnitude and its relation to concurrent shear. Across the model set, irregular buildings develop larger torsional demand and effective eccentricity than rectangular counterparts, although the level of amplification varies by configuration. The comparison clarifies how plan shape and roof form influence directional torsion and identifies cases for which direct substitution by a rectangular plan becomes unreliable in MWFRS evaluation of irregular low-rise buildings [1–3].

Keywords: wind-induced torsion; low-rise buildings; irregular plan shapes; MWFRS

References:

[1] M. Elsharawy, K. Galal, T. Stathopoulos, *Torsional and shear wind loads on flat-roofed buildings*, Engineering Structures 84 (2015) 313–324. DOI: 10.1016/j.engstruct.2014.11.028.

[2] M. Matus, I. Zisis, *Wind-Induced Pressure Distribution of Nonrectangular Shaped Low-Rise Buildings*, Journal of Structural Engineering 152(5) (2026) 04026031. DOI: 10.1061/JSENDH.STENG-14906.

[3] M. Abdallah, I. Zisis, M. Matus, *Wind-Induced Torsional Loads on Irregular-Shaped Mid-Rise Buildings*, 15th Americas Conference on Wind Engineering, 2025. DOI: 10.13140/RG.2.2.16764.86404.

Probabilistic DEM Investigation of Rubber–Soil Mixtures for Optimizing Shallow Foundation Performance

Fedor Maksimov[a], Alessandro Contento[b], Bruno Briseghella[b] & Pierfrancesco Cacciola[b]

[a] School of Architecture, Technology and Engineering, University of Brighton, Brighton, UK
[b] College of Civil Engineering, Fuzhou University, Fuzhou, China

E-mail: alessandro@fzu.edu.cn.

Abstract

Rubber–soil mixtures (RSM) have recently attracted interest as sustainable geomaterials capable of modifying soil stiffness and damping. Their potential use in geotechnical seismic isolation and foundation systems depends strongly on the internal granular structure and on the proportion of rubber particles, both of which influence soil–structure interaction (SSI) mechanisms. However, the mechanical response of such mixtures is inherently affected by uncertainties in particle arrangement and granulometric distribution. This study investigates how variability in particle distribution and rubber content affects the behaviour of shallow foundations resting on RSM layers [1]. Numerical simulations are conducted using the Discrete Element Method, where granular assemblies are generated as stochastic particle clouds consistent with prescribed particle-size distributions. A Monte Carlo framework is adopted to represent uncertainty in particle placement and packing configurations. Results show that foundations resting on RSM layers exhibit reduced variability in translational and rotational stiffness compared with natural gravel soils and lead to lower seismic demand in terms of base displacement, rotation, and base moment. Parametric analyses are also conducted for different rubber contents in order to identify the percentage of RSM that optimizes structural performance, balancing stiffness reduction, energy dissipation capacity, and foundation stability.

Keywords: Geotechnical Seismic Isolation; Nonlinear soil-structure interaction; Distinct Element Method; Soil uncertainty

References:

[1] Maksimov, F., Contento, A., Briseghella, B., Cacciola, P. (2026). Nonlinear soil-structure interaction in geotechnical seismic isolation: A two-stage DEM-Preisach formalism framework, Comput. Struct., 323: 108159.

Advancing the Modeling of Metallic Foam Claddings for Blast Mitigation: From Shock Front Theory to Discrete Spring-Lumped-Mass Modeling

Ola Wattad[a], **Hezi Y. Grisaro**[a]

[a] Faculty of Civil Engineering, Technion-Israel Institute of Technology, Haifa, Israel

E-mail: olawattad@campus.technion.ac.il

Abstract

Metallic Foams are widely recognized in the field of engineering mechanics for their exceptional energy-absorption capabilities, stemming from their unique cellular architecture. When employed as sacrificial claddings, these materials mitigate structural damage by attenuating peak blast pressures through controlled plastic compaction. While the Shock Front Theory (SFT) has traditionally served as a foundational, low-order analytical tool for predicting this behavior, its continuum-based, two-correlated degrees-of-freedom nature often obscures complex, localized phenomena inherent in cellular solids. This study discusses a high-fidelity modeling approach based on the Spring-Lumped Mass-Theory (SLMT). By discretizing the foam cladding into a multi-degree-of-freedom system, the model captures intricate mechanical responses, including localized-inertia effects, local "stress enhancement" phenomenon, internal wave reflections and the generation of multiple shocks. In this study, a comprehensive comparison between the SFT and SLMT frameworks is established for different case studies, using performance analysis of loading combinations. Results corroborate findings from previous studies regarding the applicability of the SFT, demonstrating excellent agreement with the high-order SMT approach, specifically in the high-pressure, short-duration regime characteristic of blast loading. The findings delineate the regimes where simplified models suffice and where high-order discrete modeling is critical for capturing the deformation-contact process and densification spikes, providing a refined methodology for the resilient design of structures subjected to extreme dynamic environments.

Combinatorial cyber-physical shape optimization for tall buildings using hybrid aerodynamic strategies

Wei-Ting Lu [a], **Brian M. Phillips** [b] **& Zhaoshuo Jiang** [c]

[a] Department of Mechanical and Electromechanical Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan

[b] Department of Civil and Coastal Engineering, University of Florida, Gainesville, United States

[b] School of Engineering, San Francisco State University, San Francisco, United States

E-mail: weiting.lu@mail.nsysu.edu.tw

Abstract

For high-rise buildings, the need to apply aerodynamic strategies to mitigate wind-induced responses is well recognized. Effective methods include corner recession, setback, and venting. For example, the standard deviation of the across-wind base moment (σ_{CML}) can be reduced by 32% for a tall building with a 10% corner-recession modification ratio applied throughout the height, while a reduction of 35% can be achieved for a building with a venting floor. However, the benefits of these strategies have primarily been studied individually in the literature. Limited studies have focused on the effectiveness of applying more than one aerodynamic strategy (referred to as a hybrid aerodynamic strategy) to tall buildings. To fill this research gap, the objective of this study is to investigate the benefits of applying a hybrid aerodynamic strategy that combines corner recession and venting. Due to the large design space, a combinatorial aerodynamic shape optimization (ASO) problem for tall buildings was formulated. To ensure practical applicability in industry, a constraint enforcing a fixed building volume was imposed in the ASO problem. The objective function was defined as minimizing σ_{CML} . A cyber-physical ASO procedure integrated with a customized two-element switch algorithm was developed. The algorithm ensures optimization convergence within an affordable number of function evaluations, making it promising for ASO problems that rely on expensive evaluation tools such as boundary layer wind tunnel (BLWT) testing or computational fluid dynamics. To demonstrate the robustness of the proposed procedure, two case studies were conducted. A total of 119 models were tested over seven working days in the BLWT at the University of Florida. Compared with the benchmark model, the objective function was reduced by 52%, outperforming buildings employing the individual aerodynamic strategies mentioned above. Beyond identifying the optimal solution, practical insights regarding the sequencing of venting and the variation of building cross-sections along the height are also discussed.

Keywords: combinatorial aerodynamic shape optimization, wind tunnel testing, high-rise building

Rolling and impact dynamics of quasi-globular solids for the protection of the Millefiori Vesuvian Cups

Ester Sallicandro [a], Roberto Serpieri [b]

[a] Department of Engineering, University of Sannio, ITALY

[b] Department of Architecture and Industrial Design, University of Campania "Luigi Vanvitelli", ITALY

E-mail: e.sallicandro@studenti.unisannio.it, roberto.serpieri@unicampania.it

Abstract

This contribution proposes analytical and numerical methods for the analysis of rolling and impact of unilaterally supported hollow-globular solids subjected to base excitations. The presented methods are tailored upon the engineering design problem of protecting brittle museum artifacts having both smooth and non-smooth boundary regions, as well as convex and non-convex regions, such as vases and bowls of predominantly globular shape belonging to the archaeological Vesuvian collections, like the Coppa Millefiori and Scodella Millefiori exhibited at the National Archaeological Museum of Naples [1]. Extending methodologies previously investigated by the authors for the rigid rolling heavy half-disk model subjected to horizontal excitations, and for semi-elliptical planar geometries [2], higher-order polynomial interpolation are employed in this contribution for describing the diametral-section rolling-mechanics of cylindrical solids having more general smooth convex geometries. The impact problem determined by the presence of non-convex and non-smooth boundary regions is also examined proceeding from a critical reassessment, carried out in the light of the canonical principles of Rational Mechanics, of the 1963 impact formulation proposed by Housner which has found wide employment in mathematical applications aimed at the protection of the archaeological and museum heritage and for modelling the dynamics of larger block structures [3].

Keywords: Mechanical modeling · Computational Analysis · Protection of museum artifacts

References:

[1] S. De Caro, The National Archaeological Museum of Naples, 1994, pp. 201–203, 236–237.

[2] E. Sallicandro, A. Luciano, R. Serpieri, Dynamic Modeling of Globular Freestanding Solids for the Protection of Museum Exhibits: The Case Study of the MANN Millefiori Cup, in: Proceedings of AID MONUMENTS, 2025, accepted September 2025.

[3] D. Liberatore, Vulnerabilità dei beni archeologici e degli oggetti esibiti nei musei, Roma, CNR-Gruppo Nazionale per la Difesa dai Terremoti, 2000, pp. 1–118.

MS4

A 3D finite element coupled thermo-hygro-mechanical and neutron diffusion model for neutron-induced expansion of concrete at the mesoscale

Abderrahmane Lahmar [a], **Benoît Bary** [a], **Tulio Honorio**[a]

[a] Université Paris-Saclay, CEA, Service de recherche en Corrosion et Comportement des Matériaux, 91191 Gif Sur Yvette, France

E-mail: abderrahmane.LAHMAR@cea.fr

Abstract

Concrete is an essential material in the design and construction of nuclear facilities. It is widely used, from foundations and basemats to containment structures, biological shielding slabs, and spent fuel pools. In French nuclear power plants, the concrete biological shield is primarily designed to support the reactor vessel and to attenuate radiation. Within the framework of ongoing efforts to extend the service life of nuclear power plants, this work aims to develop modelling approaches at both material mesoscale and macroscale. At the mesoscale, dedicated numerical models and methods will be implemented to investigate the effects of aggregate swelling due to neutron irradiation on microcracking in the bulk cement paste and at paste–aggregate interfaces, as well as the resulting impact on the overall mechanical behavior of concrete. Building on the numerical model proposed by (Bary et al., 2024), the main objectives are to develop a streamlined model for neutron diffusion in concrete, to account for the influence of damage on neutron transport and heat transfer properties and to improve the modelling of the cementitious matrix, with a particular focus on microcracking, by relying on computationally lean microscale models suitable for efficient simulations. The model will be validated against experimental data obtained from controlled neutron irradiation campaigns reported by (Maruyama et al., 2017), with the aim of comparing the evolution of mechanical properties, in particular the residual Young's varied modulus, as well as compressive and tensile strengths. Neutron flux and gamma dose will be in order to cover a wide range of irradiation conditions.

Keywords: Concrete biological shield, Neutron irradiation, Multi-scale modelling, Irradiated concrete.

References:

[1] Bary, B., Sanahuja, J., Le Pape, Y., 2024. Mesoscale modelling and simulation of irradiation induced expansion in concrete. International Journal of Mechanical Sciences 283, 109646. https://doi.org/10.1016/j.ijmecsci.2024.109646

[2] Maruyama, I., Kontani, O., Takizawa, M., Sawada, S., Ishikawao, S., Yasukouchi, J., Sato, O., Etoh, J., Igari, T., 2017. Development of Soundness Assessment Procedure for Concrete Members Affected by Neutron and Gamma-Ray Irradiation. ACT 15, 440–523. https://doi.org/10.3151/jact.15.440

Implementation Of A Dynamic Particle Packing Concept For Derivation Of Particle-Based Mesoscopic-Discrete Models

Saeid Mehrpay [a], Jelle Billiet [a], Daniele Pelessone [b], Jan Vorel [c] & Roman Wan-Wendner

[a] Department of Structural Engineering and Building Materials, Ghent University, Ghent 9052, Belgium

[b] Engineering and Software System Solutions, Inc. (ES3), San Diego, CA 92101, US

[c] Department of Mechanics, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, Prague 16629, Czech Republic

E-mail: roman.wanwendner@ugent.be

Abstract

The mesoscopic modeling approach for simulating concrete has been implemented to capture a wide range of phenomena involving particles, cementitious mortar, and their potential interactions with mechanical and environmental deterioration phenomena. Generating the aggregates based on the targeted gradation is the initial step to derive these models. Utilizing a random particle placement algorithm in such cases is a simple and widely used approach. Such methods, while effective, can cause a bottleneck when a dense particle gradation is needed. On top of that, the particle placement becomes progressively slower as more particles are placed in the designated volume until the model is saturated, making further progress practically impossible. This will limit the range of particles or the possible range of Fuller's coefficient that can be implemented in the study. In this investigation, a novel concept of dynamic packing of growing particles is being developed. This approach does not rely solely on random particle placement, but combining it with a growing algorithm can reduce computational time. After initially spawning, the aggregates will grow and interact based on the defined time-dependent behavior. To demonstrate the applicability of this concept, the growing particle packing is benchmarked and compared to the conventional approach. On top of that, the effectiveness of this approach in challenging particle densities and Fuller's gradation coefficient, alongside possible influences of the wall effect, is investigated and compared to the conventional method.

Keywords: discrete-mesoscopic modeling, particle packing, lattice-discrete particle model

Multiphysics Response of Fiber-Reinforced Concrete Under Extreme Thermal Loading: A Review

Nunzia Gargiulo [a], Antonio Cibelli [a] Donatella de Silva [a] & Emidio Nigro [a]

[a] Department of Structures for Engineering and Architecture, University of Naples Federico II

E-mail: *nunzia.gargiulo@unina.it*

Abstract
The structural durability of cement-based infrastructures, such as tunnel linings, is strictly de-pendent on the material's response to complex environmental conditions. Under fire exposure, concrete behaves as a multiphase porous medium where coupled thermo -hygro-mechanical phenomena govern the risk of explosive spalling [1]. This study reviews the state-of-the-art in modelling these multiphysics interactions, shifting the focus from purely empirical observations to the fundamental physical processes that compromise concrete integrity. The analysis investi-gates the synergy between three primary mechanisms: (i) heat and mass transport, leading to pore pressure build-up as interstitial water undergoes phase transition; (ii) thermo-mechanical coupling, where steep thermal gradients induce restrained expansion; and (iii) chemical degra-dation of the cementitious matrix at elevated temperatures [2]. In this context, the inclusion of fibers is treated as a fundamental modification of the material's multiphysics pro perties. The review explores how fiber melting, particularly polypropylene, alters the connectivity of the pore network at approximately 170°C, effectively transforming the transport properties of the me-dium to relieve internal pressures [3]. By synthesizing experimental data on hybrid fiber-rein-forced concrete (FRC), this work identifies the critical parameters for robust numerical simula-tions. The goal is to provide a comprehensive framework for predicting the performance and resilience of reinforced concrete structures specifically subjected to extreme thermal loading and fire scenarios.

Keywords: Multiphysics Modelling, Thermo-Hygro-Mechanical Coupling, Concrete Durability, High Temperatures, Explosive Spalling.

References:

[1] N. Hua, A.F. Tessari, N. Elhami-Khorasani, Damage Assessment Framework for Tunnel Structures Subjected to Fire, SiF 2020.
[2] Z. Yan, Y. Shen, H. Zhu, X. Li, Y. Lu, Experimental Investigation of Reinforced Concrete and Hybrid Fibre Reinforced Concrete Shield Tunnel Segments Subjected to Elevated Temperature, Fire Safety J. 71 (2015) 86–99.
[3] P. Kalifa, G. Chéné, C. Gallé, High-Temperature Behaviour of HPC with Polypropylene Fibres: From Spalling to Micro-structure, Cem. Concr. Res. 31 (2001) 1487–1499.

A Discrete Multiphysics Model for Chloride Penetration in Damaged UHPC

Antonio Cibelli [a], Liberato Ferrara [b] & Giovanni Di Luzio [b]

[a] Dept. of Structures for Engineering and Architecture, University of Naples 'Federico II', Naples, Italy
[b] Dept. of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy

E-mail: antonio.cibelli@unina.it

Abstract

Concrete cracks in service conditions, and precisely those cracks represent preferential paths for aggressive agents to penetrate and harm both matrix and reinforcement. The inherent capacity of cementitious materials of autonomously sealing the fractures – mainly due to delayed (secondary) hydration and calcium carbonate precipitation – might result in a higher durability in aggressive environments. Recently, at the Politecnico di Milano, the effect of both autogenous and stimulated healing – mixtures enriched with healing agents – on chloride penetration has been experimentally investigated for an Ultra High-Performance Fibre-Reinforced Cementitious Composite [1]. In this research work, the whole laboratory campaign is simulated through a Multiphysics-Lattice Discrete Particle Model (M-LDPM)-based numerical model, able to simulate the autogenous and stimulated healing in ordinary and advanced cementitious materials [2]. The healing process is simulated through an improved version of the Hygro-Thermo-Chemical (HTC) model, in which the effect of cracks closure on permeability is implemented. Aiming to capture the results obtained through the afore-mentioned experimental campaign, the healing model is coupled and harmonised with an existing M-LDPM-based chloride diffusion model for saturated and non-saturated concrete [3]. The numerical results prove the model capability of capturing both the reduction of chloride penetration due to the cracks sealing, and the different degree of closure reachable with and without employing crystalline admixtures as healing agents. The research activity from which this work stems was framed into the H2020 ReSHEALience project (No 760824).

Keywords: Multiphysics Modelling, Chloride Penetration, Self-healing, Concrete Durability.

References:

[1] Cuenca, Estefanía, Francesco Lo Monte, Marina Moro, Andrea Schiona, and Liberato Ferrara. "Effects of autogenous and stimulated self-healing on durability and mechanical performance of UHPFRC: Validation of tailored test method through multi-performance healing-induced recovery indices." Sustainability 13, no. 20 (2021): 11386.

[2] Cibelli, Antonio, Liberato Ferrara, and Giovanni Di Luzio. "Multiscale and multiphysics discrete model of self-healing of matrix and interfacial cracks in fibre reinforced cementitious composites: Formulation, implementation and preliminary results." Cement and Concrete Composites 148 (2024): 105465.

[3] Zhang, Ying, Giovanni Di Luzio, and Mohammed Alnaggar. "Coupled multi-physics simulation of chloride diffusion in saturated and unsaturated concrete." Construction and Building Materials 292 (2021): 123394.

Multi-Physics Coupling Analysis of Concrete Beams Under Complex Loads and Carbonation

Li Zhu [a] & Jia-Huan Li [a]

[a] School of Civil Engineering, Beijing Jiaotong University, Beijing,

China

E-mail: zhuli@bjtu.edu.cn

Abstract

Multi-physics coupling analysis, including mechanical behavior, heat transfer, and mass transport, has garnered significant attention in durability studies of concrete bridges. Since existing research predominantly focuses on the mesoscale, prohibitive computational and modeling costs render such approaches unsuitable for analysis at the structural level. This paper proposes a macroscale strategy to investigate the mechanical performance evolution of these structures when subjected to the coupled effects of complex loads and carbonation. Based on the fixed crack theory, an external material model is developed within the COMSOL Multiphysics platform to perform refined nonlinear analysis. Employing a decoupling assumption, this model separates the mechanical behavior after cracking into tension, compression, and crack shear, incorporating the direct path integration strategy to account for fatigue effects. Three-dimensional mechanical analysis is achieved by decomposing the total strain and assembling stresses within the crack coordinate system. In parallel, the transfer of heat and the transport of moisture and carbon dioxide are implemented utilizing either built-in chemical species transport interfaces or custom partial differential equation modules. The underlying coupling mechanism primarily accounts for how cracking and temperature influence the migration of these species. Furthermore, their effects on the corrosion degree of the reinforcement are also considered, along with the impact of expansion stress induced by such corrosion on the concrete and further crack propagation. Distinct from traditional sequential coupling methods, this strategy ensures the simultaneous convergence of all physical fields within a single increment, thereby significantly reducing sensitivity associated with solution step selection.

Keywords: concrete beam, multi-physics coupling, fixed crack model, fatigue effects, carbonation

References:

[1] K. Maekawa, H. Okamura, A. Pimanmas, Nonlinear mechanics of reinforced concrete, Spon Press, London, 2003.

[2] K. Maekawa, K. Toongoenthong, E. Gebreyouhannes, T. Kishi, Direct path-integral scheme for fatigue simulation of reinforced concrete in shear, J. Adv. Concr. Technol. 4 (2006) 159–177.

Probabilistic Model and Reliability Analysis of Spalling for Concrete Elements in Fire Conditions

Enrico Cardellino [a], Marco Andreini [b], Donatella de Silva [a], Saverio La Mendola [b] & Emidio Nigro [a]

[a] Department of Structures for Engineering and Architecture of University of Naples Federico II, Corso Umberto I, 40 - 80138 Naples, Italy.

[b] European Organization for Nuclear Research (CERN), Occupational Health and Safety and Environmental Protection (HSE) Department. 1 Esplanade des Particules, 1211 Meyrin, Switzerland

E-mail: marco.andreini@cern.ch

Abstract

Concrete is a heterogeneous material, which can suffer spalling when exposed to fire of a certain severity due to hygro-thermo-mechanical phenomena. This damage is particularly relevant in underground structures and poses a significant safety risk for firefighters and post-fire investigators. Standards for design of reinforced concrete structures subject to fire action prescribe to assess spalling risk, without offering detailed methodologies to address it [1]. Referring to analogous studies from the literature [2], this work presents a novel deterministic model to predict spalling occurrence, depth, and duration based on structural and fire variables. The model's accuracy is improved through a probabilistic correction using experimental data, following a Bayesian approach [3]. A reliability-based method is developed to estimate the probability of reaching a given spalling depth under a specified fire exposure duration. The approach is applied to a real CERN case study involving the concrete lining of an underground cavern. The proposed methodology offers an efficient tool for performance-based structural fire safety assessment, enabling accurate and practical evaluation of spalling risk in both reinforced and unreinforced concrete structures.

Keywords: Concrete Spalling, Probabilistic Model, Reliability Analysis, CERN

References:

[1] European Committee for Standardization (CEN), *Eurocode 2 - Design of concrete structures - Part 1-2: General rules - Structural fire design*, CEN, 2019.

[2] M. De Poli, C. Blom and B. Lottman, "Concrete spalling failure: a coupled buckling instability and crack failure analytical model," in *Proceedings of the 6th International Workshop on Concrete Spalling due to Fire Exposure*, Sheffield, UK, 2019.

[3] P. Gardoni, A. Der Kiureghian and K. M. Mosalam, "Probabilistic Capacity Models and Fragility Estimates for Reinforced Concrete Columns based on Experimental Observations," *J. Eng. Mech,* vol. 128, p. 15, 2002

Robust Calibration of Constitutive Models Based on Full-Field Data

Lennart Linden [a], **Karl Kalina [a]**, **Jörg Brummund [a]**, **Brain Riemer [a]** & **Markus Kästner [a]**

[a] Chair of Computational and Experimental Solid Mechanics, TU Dresden

Email: lennart.linden@tu-dresden.de

Abstract

The formulation and calibration of constitutive models for materials exhibiting complex nonlinear behavior remains a challenging task in computational mechanics. Data-driven approaches have recently gained popularity for addressing this problem; however, they usually require extensive stress–strain datasets [1]. In this work, we introduce a robust two-step approach for the automated calibration of hyperelastic constitutive models that relies exclusively on quantities measurable from experiments. In the first step, data-driven identification (DDI) is used to determine stress–strain pairs from boundary conditions and displacement fields, which can be obtained via full-field measurement techniques such as digital image correlation (DIC) [2]. In the second step, the resulting data are employed to train a physics-augmented neural network (PANN) [3], which inherently satisfies the fundamental principles of hyperelasticity while offering flexibility and straightforward implementation in finite element (FE) simulations. The capabilities of the proposed framework are illustrated through several representative numerical examples. Synthetic two-dimensional data generated from reference constitutive models are processed with DDI to extract stress–strain data, which serve as training input for the PANN. The predictive performance of the calibrated network is subsequently evaluated in three- dimensional FE simulations. Furthermore, we discuss the impact of noisy input data and different loading scenarios on the identified material response, highlighting the robustness of the methodology and its practical relevance for computational modeling.

Keywords: data-driven identification, noisy data, physics-augmented neural network, hyperelasticity, material modeling

References:

[1] A. Leygue, M. Coret, J. Réthoré, L. Stainier, E. Verron, Data-based derivation of material response, Computer Methods in Applied Mechanics and Engineering 331 (2018).

[2] L. Linden, K. A. Kalina, J. Brummund, B. Riemer, M. Kästner, A dual-stage constitutive modeling framework based on finite strain data-driven identification and physics-augmented neural networks, Computer Methods in Applied Mechanics and Engineering 447 (2025).

[3] L. Linden, D. K. Klein, K. A. Kalina, J. Brummund, O. Weeger, M. Kästner, Neural networks meet hyperelasticity: A guide to enforcing physics, Journal of the Mechanics and Physics of Solids 179 (2023).

Enhanced Fracture Resistance in Aperiodic Monotile Composites with Bio-Inspired Interlocking Interfaces

Hongru Zhang [a], Yuanpeng Liu [b], Jiaming Ma [a], Ngoc San Ha [a] & Yi Min Xie [b,a]

[a] Center for Innovative Structures and Materials, School of Engineering, RMIT University, Melbourne, Australia
[b] College of Future Technologies, Hohai University, Changzhou, Jiangsu, China

E-mail: mike.xie@rmit.edu.au

Abstract

Structural composites that integrate a stiff phase with a compliant soft component provide a promising strategy to overcome the long-standing trade-off among stiffness, strength, and toughness in mechanical metamaterials. Most existing dual-phase configurations rely on traditional periodic architectures characterized by straight interfaces, which inherently constrain further mechanical performance enhancement. This limitation has motivated researchers to explore non-periodic patterns capable of achieving superior composite designs. Here we introduce an innovative aperiodic monotile composite with bio-inspired interlocking interfaces. The proposed specimens are fabricated via PolyJet 3D printing, utilizing a rigid material (VeroClear) alongside a ductile phase (Agilus30Black). A comprehensive experimental investigation reveals that our design yields remarkable improvements in fracture resistance. Specifically, the proposed composite outperforms conventional honeycomb-based and square-based composites by over one order of magnitude, achieves nearly a sixfold increase in performance compared to the aperiodic monotile composite with straight interfaces, and further improves by 148% relative to the semicircle-edge counterpart. These performance gains arise from the cooperative effects of the extended and tortuous crack trajectory induced by aperiodicity and the strong mechanical interlocking and constraint generated by biomimetic interfaces. In addition, increasing the density of the aperiodic monotile units significantly elevates stiffness, strength, and toughness, owing to the intensified hard-phase mechanical interdigitation. Overall, this study demonstrates the synergistic advantages of integrating aperiodic monotiles with bio-inspired interlocking interfacial designs.

Keywords: structural composite, aperiodic monotile, bio-inspired interlocking, fracture resistance

MS5

Intelligent Damage Identification of Stay Cables Based on Computer Vision and Multi-Modal Fusion Neural Networks

Li Zhu [a], **Jia-Huan Li** [a] **& Zhi-Ruo Cui** [a]

[a] School of Civil Engineering, Beijing Jiaotong University, Beijing,

China

E-mail: zhuli@bjtu.edu.cn

Abstract

Condition assessment of stay cables is crucial for bridge safety. As structural vibration videos contain rich dynamic and damage information, this paper proposes a novel non-contact damage identification method utilizing computer vision and multi-modal fusion neural networks. First, a complex steerable pyramid decomposes vibration videos into local phases and amplitude coefficients. High-resolution time histories are then extracted by recombining local phases into global phases. Simultaneously, mode-separated vibration video frames are generated by applying time-varying motion filtering to local phases before reconstruction. To extract high-fidelity dense mode shapes from these frames, a specialized edge recognition network, DSC-SPC-HEDNet, is developed. Finally, taking the extracted time-history and mode shape data as inputs, a neural network containing an efficient feature fusion module and a dual-task prediction head is proposed. Validated on a hybrid dataset of experimental measurements and finite element simulations, the proposed method demonstrates accurate and simultaneous identification of cable damage location and severity.

Keywords: stay cables, computer vision, damage identification, multi-modal fusion, vibration measurement

References:

[1] Z. Liu, Q. He, S. Chen, Z. Peng, W. Zhang, Time-varying motion filtering for vision-based nonstationary vibration measurement, IEEE Trans. Instrum. Meas. 69 (2019) 3907–3916.

[2] N. Wadhwa, M. Rubinstein, F. Durand, et al., Phase-based video motion processing, ACM Trans. Graph. 32 (2013) 1–10.

Acousto-ultrasonic Based Structural Health Monitoring in Corrosion Detection

Reza Goldaran [a]

[a] Civil Engineering Department, Cyprus International University, Nicosia, North Cyprus

E-mail: rgoldaran@ciu.edu.tr

Abstract

Prestressed concrete cylinder pipes (PCCPs) are broadly utilized for water and wastewater transmission. However, the main drawback of PCCPs is catastrophic failures due to corrosion of the post-tensioned rebars. The present study investigates the key results of the Acousto-Ultrasonic (AU) approach for corrosion detection in spiral rebar of the PCCP. A full-scale PCCP was made and tested in two modes: before and after applying the accelerated corrosion. Instead of an AU transducer, the Hsu-Nelson tests were carried out to generate an ultrasonic pulse known as an Artificial Acoustic Emission (AAE). AAE was conducted in both intact and corroded states to characterize rebar corrosion. Three indices of the captured signals, including peak amplitude, energy, and dominant frequencies of the waveforms, were included in both sample states. The results indicated that both peak amplitude and energy of received signals could derive misleading information, while the AE frequency is a highly effective index representing the presence of corrosion. Furthermore, it was concluded that, depending on whether it is mounted on a steel or concrete cover surface, a sensor location is one of the most crucial factors in identifying corrosion.

Keywords: Acousto-ultrasonic, Acoustic Emission, Damage Detection, Prestressed Concrete

References:

[1] D. Yao, J. Jia, F. Wu, F. Yu, Shear performance of prestressed ultra high strength concrete encased steel beams, Constr Build Mater 52 (2014) 194-201.

[2] L. Bertolini, B. Elsener, P. Pedeferri, E. Redaelli, R.B. Polder, Corrosion of Steel in Concrete, (2013).

[3] S. Ge, S. Sinha, Effect of mortar coating’s bond quality on the structural integrity of prestressed concrete cylinder pipe with broken wires, Journal of Materials Science Research 4 (2015) 59.

Robotic Mobile Sensing for Scalable Walkability Assessment of Urban Pedestrian Walkways – Case Studies from Singapore

Xudong JIAN [a,b], **Kresimir FRIGANOVIC** [b], **Navrag SINGH** [b]

[a] ETH Zurich, Department of Civil, Environmental and Geomatic Engineering, Zurich, Switzerland

[b] Singapore-ETH Centre, Future Health Technologies, Singapore

E-mail: *xudong.jian@ibk.baug.ethz.ch*

Abstract

Walkability assessment of pedestrian walkways is essential for improving mobility and supporting car-free, sustainable urban environments. In particular, for aging societies, reliable walkability evaluation is critical to ensure the safety and accessibility of pedestrian infrastructure for elderly users. However, current approaches for evaluating walkway conditions are often labor-intensive, subjective, or costly, limiting their scalability for large urban networks. To address this challenge, this study develops a robotic mobile sensing platform for automated walkability assessment of pedestrian walkways. The platform integrates an accelerometer, camera, GNSS module, and microcontroller into a compact robotic system capable of remotely controlled navigation along predefined paths and speeds. As the robot travels along walkways, it collects synchronized multimodal data, including vibration acceleration, video recordings, and satellite positioning with time stamps. Based on the collected measurements, data-driven methods are developed to estimate three key walkway characteristics: surface roughness, friction condition, and slope angle. The proposed framework enables efficient extraction of infrastructure condition indicators directly from mobile sensing data. Two field experiments conducted in Singapore demonstrate the feasibility, efficiency, and cost-effectiveness of the proposed approach. The results highlight the potential of robotic mobile sensing to support large-scale, automated evaluation of pedestrian walkability in modern urban environments.

Keywords: Robotic Mobile Sensing, Walkability Assessment, Urban Infrastructure Monitoring, Pedestrian Walkway Condition Evaluation

Adaptive refinement of railway bridge modal parameters from on-board monitoring data

Charikleia Stoura [a] **& Eleni Chatzi** [b]

[a] Department of Mechanical Engineering, Politecnico di Milano, Via La Masa 1, Milan, 20156, Italy
[b] Institute of Structural Engineering, Department of Civil, Environmental and Geomatic Engineering, ETH Zurich, Stefano-Franscini-Platz 5, Zurich, 8093, Switzerland

E-mail: charikleia.stoura@polimi.it

Abstract

Indirect monitoring of railway bridges using on-board measurements from traversing vehicles, or so-called mobile sensing, has emerged as a promising and cost-effective alternative to conventional structural health monitoring schemes. This approach enables the assessment of multiple bridges using a limited number of roving sensors and can exploit continuously available data from in-service or dedicated railroad vehicles. Early studies relied on Fourier transform analyses or frequency-domain decomposition of vehicle-acquired signals to estimate bridge natural frequencies. More advanced approaches later adopted subspace identification techniques, which aim to separate vehicle dynamics from bridge dynamics, and used the residual response between successive vehicle passages to eliminate the influence of track irregularities. Although these methods have shown strong potential for identifying bridge frequencies, their performance remains sensitive to the short duration of the vehicle–bridge interaction and to algorithmic parameters such as the chosen model order. Consequently, the estimated modal properties may be biased or unstable. In addition, most existing indirect identification approaches cannot determine mode shapes, which in many cases must be assumed a priori, thereby preventing the direct estimation of the complete set of modal characteristics from on-board measurements. To address these limitations, the present study proposes an optimization-based refinement scheme to update a priori estimates of bridge modal frequencies—from a subspace identification scheme, for example—and estimate the corresponding mode shapes. The proposed methodology first parametrizes the mode shapes of interest and then iteratively updates a set of parameters aiming at minimizing the discrepancy between measured vehicle responses and those reconstructed using a physics-based vehicle–bridge interaction model. The proposed method enables the simultaneous estimation of modal frequencies and mode shapes, thereby extending the capabilities of indirect bridge monitoring and improving the reliability of modal identification from on-board monitoring data.

Keywords: Structural Health Monitoring, On-board Monitoring, Railway Bridges, Subspace Identification, Optimization Methods

References:

[1] C.D. Stoura, S. Gres, V.K. Dertimanis, L. Ancu, E.N. Chatzi, Identification of railway bridge modal properties based solely on acceleration data from traversing trains, Mech. Syst. Signal Process. 239 (2025) 113342.

[2] N. Hansen and A. Ostermeier, Completely derandomized self-adaptation in evolution strategies, Evol. Comput. 9 (2001) 159–195.

From Component-level Information to Portfolio-scale Structural Resilience Assessment: A Measurement-Informed BIM2Struct Digital Twin Framework

Huangbin Liang [a], Kostas Vlachas [a] & Eleni Chatzi [a]

[a] Chair of Structural Mechanics & Monitoring, ETH Zurich, Switzerland

E-mail: huangbin.liang@ibk.baug.ethz.ch

Abstract

Reliable structural assessment of existing buildings is often hindered by incomplete design documentation and progressive changes in geometry and material properties over time. Such changes arise from aging, environmental exposure, and maintenance/retrofit interventions. Consequently, structural conditions become spatially heterogeneous, while conventional numerical models relying on uniform assumptions fail to capture such variability, limiting the reliability of vulnerability and resilience evaluations, particularly at a large scale. This work proposes a BIM-to-structural-analysis (BIM2Struct) pipeline to establish a digital twin framework [1] designed to systematically integrate component-level information into analysis-ready structural models. The pipeline adopts a member-oriented modeling strategy supported by post-processing connectivity rules that ensure geometric consistency, load transfer continuity, and compatibility with analytical solvers. Such a pipeline naturally enables the integration of sensing data, allowing structural information obtained from structural health monitoring (SHM) or non-destructive testing (NDT) to be stored as tagged information at the BIM component level and directly incorporated into the modeling and analysis workflow. Furthermore, structural response data (e.g., accelerations) are processed to extract damage-sensitive features (DSFs) defined from both frequency-domain transmissibility characteristics and time-domain response descriptors relative to an undamaged reference state [2]. The DSF formulation follows a physics-informed and data-driven fusion strategy: features are constructed to reflect physically meaningful changes in stiffness, modal properties, and energy dissipation, while their relationship to engineering demand parameters-based damage states is learned from nonlinear simulations. Case study indicates that incorporating component-level updates can substantially alter predicted fragility and resilience metrics. More importantly, the BIM2Struct framework enables consistent model updating and performance assessment across a population of buildings, providing a scalable pathway for regional vulnerability analysis, resilience evaluation, and decision-making under limited and heterogeneous information.

Keywords: Structural digital twin, BIM-based modelling, Component-level information updating, vulnerability and resilience

References:

[1] Huangbin Liang, Kostas Vlachas, Eleni Chatzi. A BIM2Struct Digital Twin Framework for Integrating Component-Level Information Updates into Life-Cycle Structural Vulnerability and Reliability Assessment. WCSCM 2026.

[2] Huangbin Liang, Eleni Chatzi. Measurement-informed damage tagging and resilience enhancement of RC frame structures using acceleration-based damage-sensitive features ECEE 2026.

Edge-AI-driven mobile sensing platform for real-time pavement distress assessment

Diego Rossini [a], Leonardo Iacussi [a], Emanuele Zappa [a], Alfredo Cigada [a] & Paolo Chiariotti [a]

[a] Department of Mechanical Engineering, Politecnico di Milano, Milano, Italy

E-mail: *paolo.chiariotti@polimi.it*

Abstract

This work presents a modular, multi-sensor edge-computing platform for scalable urban sensing, designed to reduce the bandwidth, latency, and to overcome all the limitations of cloud-centric pipelines by performing acquisition and AI (Artificial Intelligence) inference directly on embedded hardware. Edge processing is particularly advantageous in large-scale, distributed deployments and crowd-sensing paradigms, where vehicle fleets can operate as mobile sensing nodes that continuously sample the urban environment and transmit only compact, high-value information [1,2]. The proposed sensing system integrates two high-resolution cameras, a GNSS (Global Navigation Satellite System) receiver and an IMU (Inertial Measurement Unit) in a vehicle-mounted unit, with computation executed on an NVIDIA Jetson Orin Nano. A web-based graphical interface and backend services enable configuration, session management, and monitoring, while a multithreaded core logic supports concurrent sensor handling and a modular architecture for future extensions. As a representative use case, the road pavement distress segmentation and geo-referenced mapping has been used. Semantic segmentation is adopted to provide pixel-level delineation of pavement defects and richer geometric information than detection-only approaches. DeepLabV3 is implemented and trained with different backbone architectures on a composite dataset augmented to reflect the oblique viewpoints and visual clutter typical of vehicle-mounted acquisition. Experimental results report both system-level acquisition throughput and segmentation accuracy on unseen test data. Deployment optimizations, including quantization and TensorRT compilation, are evaluated to meet embedded real-time constraints, with FP16 inference identified as an effective balance between accuracy and throughput, enabling sufficient frame rates while minimizing accuracy degradation. A field test in an urban route validates operational robustness and produces a spatial pavement distress map derived from frame-level damage indicators. In contrast to prior mobile mapping systems that focus mainly on defect detection and selective data offloading [3], the proposed approach delivers a fully integrated onboard pipeline that performs both data acquisition and segmentation, enabling scalable fleet-based monitoring.

Keywords: pavement distress assessment, automated vision-based monitoring, Edge-AI

References:

[1] W. Shi, J. Cao, Q. Zhang, Y. Li and L. Xu, "Edge Computing: Vision and Challenges, IEEE Internet of Things Journal, vol. 3, no. 5, pp. 637-646, Oct. 2016, doi: 10.1109/JIOT.2016.2579198 .

[2] K.P. O'Keeffe, A. Anjomshoaa, S.H. Strogatz, P. Santi, C. Ratti, Quantifying the sensing power of vehicle fleets, *Proc. Natl. Acad. Sci. U.S.A.* 116 (26) 12752-12757,doi: 10.1073/pnas.1821667116 (2019)

[3] J. Li, C. Yuan, X. Wang, Real-time instance-level detection of asphalt pavement distress combining space-to-depth (SPD) YOLO and omni-scale network (OSNet), Automation in Construction, vol. 155, 2023, 105062, doi: 10.1016/j.autcon.2023.105062

Development of Scan-to-BIM Based Technology for Automated Extraction and 3D Visualization of Bridge Surface Damage Information

Gunmo Kang [a] Sangyun Song [a] Gichun Cha [a] Dongkyu Lim [b] & Seunghee Park [a,c]

[a] Department of Global Smart City, Sungkyunkwan University, Suwon, South Korea

[b] Artificial Intelligence Plus K-Construction Infrastructure Resilience Research Center, South Korea

[c] School of Civil, Architectural Engineering and Landscape Architecture, Sungkyunkwan University, Suwon South Korea

E-mail: shparkpc@skku.edu

Abstract

As the construction industry accelerates its digital transformation, the adoption of Building Information Modeling (BIM) has become increasingly prominent. Critically, there is a rising demand for automated management systems that integrate digital frameworks with advanced technologies, such as AI, to maintain aging infrastructure. Currently, bridge inspections predominantly rely on manual, labor-intensive methods involving visual checks and handwritten records, which are inefficient in terms of time and cost. To address these challenges, this study presents a technology capable of automatically inspecting and visualizing bridge conditions by integrating LiDAR based Point Cloud Data (PCD) with deep learning models. The methodology involves three main steps: acquiring and refining 3D PCD using a Terrestrial Laser Scanner and Statistical Outlier Removal (SOR); employing a Dynamic Graph CNN (DGCNN) model to automatically segment minute crack features based on spatial relationships; and systematically mapping the extracted damage objects into a Building Information Modeling (BIM) environment as Industry Foundation Classes (IFC) standard parameters via Dynamo. Experimental results demonstrate the efficacy of the proposed approach. In laboratory tests using concrete beam specimens, the DGCNN model achieved an overall accuracy of 88.87% and a recall of 90.25%, proving its practical suitability for identifying critical damages. Furthermore, field experiments on an in-service bridge confirmed the successful integration of unstructured damage data into a structured BIM database. This approach is expected to facilitate the real-time digitization of bridge conditions, systematic accumulation of maintenance history, and the formulation of strategic maintenance plans.

Keywords: Scan-to-BIM, PCD(Point Cloud Data), Defect Data, Deep Learning

References:

[1] Wang, Y., Sun, Y., Liu, Z., Sarma, S. E., Bronstein, M. M., & Solomon, J. M. (2019). Dynamic graph CNN for learning on point clouds. ACM Transactions on Graphics (tog), 38(5), 1-12.

[2] Tang, P., Huber, D., Akinci, B., Lipman, R., & Lytle, A. (2010). Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques. Automation in construction, 19(7), 829-843.

[3] Zang, H., Lee, G., & Lee, K. (2023). A comparative analysis of BIM adoption in South Korea between 2020 and 2023. Proceedings of the Architectural Institute of Korea Conference, 43, 984–985.

LiDAR–Vision Fusion for Automated Digital Twin Updating of 3D Defects

Dongyoung Ko [a], **PaPa Win Aung** [b], **Khoa Tran Dang Vo** [a], **Changjun Lee** [a] **& Seunghee Park** [c]

[a] Department of Global Smart City, Sungkyunkwan University, Suwon, Republic of Korea
[b] E&I Structural&Civil ENG Group, Samsung E&A, Seoul, Republic of Korea
[c] School of Civil, Architectural Engineering & Landscape Architecture, Sungkyunkwan University, Suwon, Republic of Korea

E-mail: shparkpc@skku.edu

Abstract

Accurate and up-to-date representation of structural conditions is critical for reliable structural health monitoring and maintenance planning. However, existing approaches for defect inspection often rely on image- or LiDAR-only reconstruction methods, which suffer from scale ambiguity or limited geometric accuracy, thereby hindering precise defect localization in 3D space. To address these limitations, this study proposes a LiDAR–handled camera fusion framework for automated digital twin updating of 3D defects. The proposed method integrates LiDAR scanning with handheld camera imagery to leverage complementary strengths: LiDAR provides metric-scale geometric information, while vision- based models enable precise defect detection and segmentation. A multi-modal registration pipeline aligns LiDAR point clouds, image data, and Building Information Modeling (BIM) coordinates within a unified reference frame. Detected defects are projected into a 3D model, enabling accurate localization and quantitative assessment of defect size. The extracted defect information is then directly registered within the BIM environment, allowing automated updates of defect attributes and spatial information. Experimental results demonstrate that the proposed framework achieves high accuracy in 3D defect localization and consistent quantification compared to conventional single-sensor-based methods. The fusion framework requires LiDAR scanning only once for initial synchronization with vision data. Thereafter, defect updates throughout the entire lifecycle of the structure can be continuously performed using only handheld camera scanning. Additionally, localized defects are incorporated as BIM elements via Revit, enabling their direct use in finite element method FEM and structural analysis tools.

Keywords: Defect localization, Digital twin, BIM registration

References:

[1] Chen, Junjie, Shuai Li, and Weisheng Lu, Align to locate: Registering photogrammetric point clouds to BIM for robust indoor localization, Building and Environment, 209 (2022) 108675.
Reference to a book:

[2] Xu, Lei, et al, Automatic defect localization method based on BIM projected image, Advanced Engineering Informatics, 69 (2026) 103874.
Reference to a Chapter in a volume:

[3] Chen, Junjie, Weisheng Lu, and Jinfeng Lou, Automatic concrete defect detection and reconstruction by aligning aerial images onto semantic rich building information model, Computer-Aided Civil and Infrastructure Engineering, 38 (8) 1079- 1098.

Wavelet-Based Crack Detection Using Improved Phase-Based Optical Flow

Sung-min Eom [a], **Dong-heon Yang** [a], **Sang-heon Lee** [a], **Kyung Ho Sun** [b] **& Yun-ho Shin** [a]

[a] Department of Naval Architecture & Ocean Engineering / GCRC-SOP, Pusan National University, Busan 46241, South Korea

[b] AX Convergence Research Center, Korea Institute of Machinery & Materials, Daejeon 34103, South Korea

E-mail: shinyh77@pusan.ac.kr

Abstract

Early detection of micro-cracks is essential for maintaining the structural integrity and operational safety of structures. Conventional non-destructive testing (NDT) techniques, such as ultrasonic testing (UT) and acoustic emission (AE), are effective for localized inspection but often face limitations in large-scale structures due to restricted accessibility and limited spatial coverage. Vibration-based crack detection methods have therefore been widely investigated, where structural damage is identified through singularities or changes in mode shapes. Image-based vibration measurement techniques have been increasingly explored to extract vibration signals required for deriving structural mode shapes with high spatial resolution. However, measurement noise can adversely affect crack detection by distorting crack-induced singularities, which makes accurate crack identification difficult. This study proposes a wavelet-based crack detection framework based on improved phase-based optical flow. Phase unwrapping and additional filtering techniques are incorporated into the phase-based optical flow process, enabling more stable and accurate vibration extraction. The derived structural mode shapes are subsequently analyzed using wavelet functions, which allows crack-induced changes to be identified even under noisy imaging conditions. A multi-mode approach is considered to emphasize crack-related features while further suppressing image-based measurement noise. The proposed approach was experimentally examined using cantilever beam specimens with cracks of varying sizes and locations to evaluate spatial concentration characteristics and localization accuracy. The results demonstrate the feasibility and applicability of the proposed framework for crack detection, highlighting its potential for practical structural health monitoring applications.

Keywords: Vision-based Vibration Extraction, Crack Detection, Wavelet function

Acknowledgments:

This study was supported by 2025 Ministry of Oceans and Fisheries (MOF) of the Marine Blue Tech Future Leader Training Project 'Training Blue Tech Leaders for Eco-Friendly Ships (No. RS-2025-02220459), Korea and the main research project of Korea Institute of Machinery & Materials (No. NK263C).

MS6

Accelerating phase-field fracture simulations with the Integrated Finite Element Neural Network (IFENN)

Panos Pantidis[a], **Fouad Amin**[a], **Diab Abueidda**[a], **& Mostafa E. Mobasher**[a]

[a] Civil and Urban Engineering, New York University Abu Dhabi, Abu Dhabi, UAE

E-mail: pp2624@nyu.edu

Abstract

In this work, we implement the Integrated Finite Element Neural Network (I-FENN) framework [1-3] to simulate the complete phase-field crack evolution, capturing both the initiation and propagation stage. I-FENN augments a typical FEM solver which computes the displacement field, with a pre-trained neural network which predicts the phase-field map in a tightly coupled staggered scheme. Here, we utilize a DeepONet with Kolmogorov-Arnold Networks in the branch and trunk (DeepOKAN) for the initiation stage, while propagation is captured with the utilization of Convolution Neural Networks (CNNs). Both types of networks are trained on the same setup: the maximum strain energy density is mapped to the phase-field variable using an extremely small number of training samples and pure strong-form physics-informed principles. Through a strategic choice of network design parameters – including proper activation functions, post-process Gaussian filters and optimized point sampling – we achieve strong generalization capabilities with remarkably fast training. Specifically, we show that a single training on the single-notch tension problem is sufficient to deploy the same trained network across diverse geometries, multiple crack locations and trajectories, and load incrementation schemes.

Keywords: scientific machine learning, physics-informed, phase-field fracture, hybrid modeling

References:

[1] Pantidis, P. & Mobasher, M.E. (2023). Integrated Finite Element Neural Network (I-FENN) for non-local continuum damage mechanics. Computer Methods in Applied Mechanics and Engineering, 404, 115766.

[2] Pantidis, P., Eldababy H., Abueidda, D. & Mobasher, M.E. (2024). “I-FENN with Temporal Convolutional Networks: Expediting the load-history analysis of non-local gradient damage propagation”. Computer Methods in Applied Mechanics and Engineering, 425, 116940.

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

Solving Elasto-Plastic Layered Contacts via Physics-Data Hybrid Neural Network

Shaoqi Huang, **Haoyu Gu, Siyang Song, Chongpu Zhai, Minglong Xu**

State Key Laboratory for Strength and Vibration of Mechanical Structure, School of Aerospace Engineering, School of Aerospace Engineering, Xi'an Jiaotong University, Xi'an 710049, China

E-mail: *zhaichongpu@xjtu.edu.cn*

Abstract

Predicting the elasto-plastic contact behavior of layered rough surfaces is crucial for advanced manufacturing, tribology, and surface engineering. However, high-fidelity numerical methods are computationally prohibitive for multi-scale problems, while purely data-driven deep learning models often yield physically inconsistent results, such as "ghost deformations" in non- contact regions, and struggle to generalize across different material pairs. To address this fundamental bottleneck, we propose a novel "grey-box" hybrid neural network architecture that seamlessly embeds classical contact mechanics directly into the deep learning pipeline. The proposed model explicitly decomposes the total surface deformation into a global elastic field and a local nonlinear plastic residual. The elastic component is computed exactly using a differentiable, batch-parallelized Fast Fourier Transform (FFT) physical layer based on frequency- domain transfer matrices for layered media. Concurrently, a Residual U-Net equipped with spatial attention mechanisms predicts the highly nonlinear plastic deformation. To guarantee physical compliance, we introduce a Hard Gating Mechanism that strictly enforces the Karush- Kuhn-Tucker (KKT) complementarity conditions, forcing plastic residuals to zero in non-contact zones. Furthermore, to achieve universal generalization across varied material combinations and coating thicknesses, we implement a Physics-Informed Feature Modulation (PIFM) module. This module extracts dimensionless physical parameters-including layer-substrate stiffness mismatch, effective indenter rigidity, and macroscopic dimensionless thickness-to dynamically modulate the convolutional feature maps according to the underlying physical environment. Experimental results demonstrate that the proposed hybrid solver achieves accuracy comparable to rigorous numerical methods while accelerating inference time from hours to milliseconds. The dimensionless feature injection enables exceptional zero-shot generalization to unseen material pairs and indenter geometries. Ultimately, this physics-embedded framework resolves the trade- off between computational speed and physical fidelity, offering a robust, interpretable solver for real-time contact analysis and digital twin applications.

Keywords: Layered Rough Surfaces, Elasto-Plastic Contact, Physics-Informed Deep Learning.

References:

[1] Nath D, Ankit, Neog DR, Gautam SS. Application of Machine Learning and Deep Learning in Finite Element Analysis: A Comprehensive Review: D. Nath et al. Archives of computational methods in engineering 2024, 31(5): 2945-2984.:

[2] Zhou Y, Song H. Data-driven enhanced rough contact mechanics: PINN estimation of gap distribution across length scales for partial contacts. Tribology International 2025: 111100:

[3] Bonagiri LKS, Wang Z, Zhou S, Zhang Y. Precise surface profiling at the nanoscale enabled by deep learning. Nano letters 2024, 24(8): 2589-2595.

[4] Sahin T, Wolff D, Popp A. Physics-informed neural networks for solving contact problems in three dimensions. Advances and Challenges in Computational Mechanics. Springer, 2026, pp 419-431.

A Unified Differentiable Computational Mechanics Framework: From Physics-Informed Neural PDE Solvers to Neural-Embedded Material Point Methods

Yuming Zhang [a], Jiaji Wang [a*], Mingyu Wang [a], Xiaoge Tian [a] & Si Fu [a]

[a] Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

E-mail: yuming_zhang@connect.hku.hk

Abstract

Accurate and efficient modeling of forward and inverse problems in nonlinear solid mechanics remains challenging due to convergence issues in neural PDE solvers and the difficulty of identifying constitutive behavior under large deformation. A differentiable computational mechanics framework is developed to address these limitations by integrating physics-informed neural networks with particle-based numerical methods. Enhanced PINN architectures, including EPINN and Bayesian-optimized AEPINN, enforce exact Dirichlet boundary conditions, reduce trainable parameters via tensor decomposition, and automate hyperparameter tuning, significantly improving stability and computational efficiency. These models achieve substantial speedup over conventional PINNs while maintaining accuracy comparable to FEM for complex 2D and 3D structures and hyperelastic materials. To extend differentiability to strongly nonlinear and history-dependent problems, the Material Point Method (MPM) is reformulated in a fully differentiable manner. Neural networks are embedded into the stress-update kernel to replace or augment classical constitutive laws, and automatic differentiation through the complete P2G–grid update–G2P cycle enables gradient-based material identification. The resulting framework unifies neural PDE solvers and differentiable particle mechanics, advancing data-driven constitutive modeling and inverse analysis in computational solid mechanics.

Keywords: Physics-informed neural network (PINN), Exact Dirichlet boundary PINN (EPINN), Differentiable Material Point Method

References:

[1] Tian, X., Wang, J., Kim, C. W., Deng, X., & Zhu, Y. (2025). Automated machine learning exact dirichlet boundary physics-informed neural networks for solid mechanics. Engineering Structures, 330, 119884.

[2] Gavris, G. B., & Sun, W. (2025). Discovering neural elastoplasticity from kinematic observations. Proceedings of the National Academy of Sciences, 122(38), e2508732122.

[3] Zhang, T., Yu, H. X., Wu, R., Feng, B. Y., Zheng, C., Snavely, N., ... & Freeman, W. T. (2024, September). Physdreamer: Physics-based interaction with 3d objects via video generation. In European Conference on Computer Vision (pp. 388-406). Cham: Springer Nature Switzerland.

Exact Boundary Conditions Physics-informed Solver for Elastodynamics

Xiaoge Tian [a], Jiaji Wang [a], Yuming Zhang [a], Si Fu [a] & Mingyu Wang [a]

[a] The University of Hong Kong

Department of Civil Engineering, The University of Hong Kong, Hong Kong, China

E-mail: *cewang@hku.hk*

Abstract

Conventional Physics-informed machine learning has gained great achievement in accelerating the forward and inverse solving procedures of scientific problems. Physics-informed Neural Network (PINN) is mesh-free deep learning framework in constraining physics partial differential equations and boundary conditions in soft manner. Previously, approximate distance function was proposed to impose the exact Dirichlet boundary conditions for solving static problems by researchers. Exact Dirichlet boundary condition PINN (EPINN) has been developed to leverage the strength of hard constraints in defining the interpolation function to ensure EPINN can exactly meet the boundary values of displacement. However, such framework is more suitable for obtaining static solution fields without time increment. In this study, a framework considering initial condition, Dirichlet boundary condition, and Neumann condition is developed based on the Approximate Distance Function (ADF). Through utilizing the ADF function, the boundary of irregular shaped geometry can be well discovered. The Exact boundary conditions Physics- informed Solver (EPS) is constructed with exact initial condition function and mix variables mechanism to predict the displacements, strains, and stresses simultaneously to fully evaluate the structural responses under external loadings. Compared with PINN, EPS can solve the elastodynamics problems without labeled data and achieve significant speedup.

Keywords: PINN, EPINN, ADF, initial condition, boundary conditions, EPS, elastodynamics

References:

[1] Sukumar, N., & Srivastava, A. (2022). Exact imposition of boundary conditions with distance functions in physics-informed deep neural networks. Computer Methods in Applied Mechanics and Engineering, 389, 114333.:

[2] Wang, J., Mo, Y. L., Izzuddin, B., & Kim, C. W. (2023). Exact Dirichlet boundary physics-informed neural network EPINN for solid mechanics. Computer Methods in Applied Mechanics and Engineering, 414, 116184.:

Integrated Finite Element Neural Networks (I-FENN) for Efficient Multiphysics Simulation

Mostafa E. Mobasher, **Panos Pantidis, Diab W. Abueidda, Habiba Eldababy, Fouad Amin**

Civil and Urban Engineering Department, New York University Abu Dhabi, Abu Dhabi, P.O. Box 129188, United Arab Emirates

Abstract

Many engineering problems involve tightly coupled multiphysics processes and nonlinear material behavior, making their numerical solution computationally demanding when modeled using conventional high-fidelity methods. To address this challenge, the Integrated Finite Element Neural Network (I-FENN) framework introduces a hybrid computational strategy that combines the reliability of the finite element method (FEM) with the predictive efficiency of neural networks. Within this framework, a pre-trained neural network is embedded into the finite element solution procedure in a staggered formulation: FEM resolves the mechanical equilibrium equations while the neural network approximates the evolution of coupled or auxiliary physical fields. By replacing selected partial differential equation solves with fast neural network inference, the approach reduces the number of global degrees of freedom and significantly accelerates multiphysics simulations. The I-FENN methodology has been successfully applied to a wide range of coupled problems, including thermoelasticity, poroelasticity, and nonlinear fracture mechanics. In these applications, neural networks serve as surrogate solvers for governing equations describing processes such as heat transfer, pore pressure diffusion, and phase-field evolution. Their predictions are incorporated into the finite element system as internal material variables, enabling the coupled response to be resolved while retaining the stability and numerical rigor of the FEM formulation. Recent advances further enhance the framework through the use of operator-learning architectures and physics-informed convolutional neural networks that improve generalization across boundary conditions, loading paths, and geometric configurations. By learning spatial relationships between mechanical energy measures and auxiliary fields, these models can accurately capture complex interactions without explicit time-stepping of the auxiliary physics. Benchmark studies across several multiphysics settings demonstrate that the I-FENN approach delivers substantial computational speedups while maintaining high predictive fidelity. Overall, the I-FENN framework provides a physics-consistent and scalable pathway for integrating machine learning with established numerical methods, enabling efficient simulation of large-scale multiphysics problems in engineering mechanics.

References:

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

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

[3] Pantidis, P., & Mobasher, M. E. (2023). Integrated Finite Element Neural Network (I-FENN) for non-local continuum damage mechanics. *Computer Methods in Applied Mechanics and Engineering*, *404*, 115766.

MS7

Tornado-like Vortices Modeling in Straight-line Simulators: An Alternative Approach

Mohammad Abid Hasan[a], Faiaz Khaled [a] & Franklin T. Lombardo [b]

[a] Texas Tech University, Lubbock, TX, USA
[b] University of Illinois at Urbana-Champaign, Urbana, IL, USA

E-mail: *has24395@ttu.edu*

Abstract

Transient and non-stationary wind events such as tornadoes, hurricanes, and thunderstorms lead to major property damage ($45.7 billion annually) and loss of life in the United States (NOAA National Centers for Environmental Information (NCEI), 2025). Due to the lack of near-surface data, accurately modeling the near-surface features of these events is essential for engineering applications. To study tornado-induced loading, researchers in the engineering community traditionally rely on the tornado-vortex generators (TVGs) to numerically and physically simulate tornado-like vortices (TLVs). Although TVGs contribute significantly to the community regarding TLVs and induced loading, they are constrained by several limitations [1], particularly in generating TLVs at realistic translation speeds. To address these limitations, a unique TLV generation mechanism [2,3] in a straight-line wind tunnel is investigated using large eddy simulation (LES). The fundamental concept is to modify the wind tunnel by installing a blockage mechanism, which includes a set of actuating louvers. The blockage mechanism introduces horizontal shear instability (HSI) into the flow field, ultimately generating a TLV with realistic translation speed in the downwind region of the computational domain. This study uses the arbitrary-mesh interface (AMI) dynamic-mesh technique to simulate the rotating louvers, which has been a long-standing challenge in the engineering community. The characteristics of the generated TLVs are validated based on the three widely recognized criteria of TLVs: (a) radial profile of pressure, (b) radial profile of tangential velocity, and (c) vertical profile of resultant velocity at the radius of maximum wind (RMW). The generated TLVs demonstrate strong repeatability and conform well to field observations and analytical models. The proposed method successfully generates TLVs with realistic translation speeds, maintaining similarity with field observations. This method will advance the understanding of TLVs with realistic features and their effects on the built environment.

Keywords: Tornado-like vortex (TLV), Large Eddy Simulation (LES), Dynamic Mesh, Transient Wind Events.

References:

[1] C. Baker, M. Sterling, Are Tornado Vortex Generators fit for purpose?, Journal of Wind Engineering and Industrial Aerodynamics 190 (2019) 287–292. https://doi.org/10.1016/j.jweia.2019.05.011.

[2] F. Khaled, F.T. Lombardo, K. Gurley, Modeling of vortices in straight-line wind simulators, Journal of Wind Engineering and Industrial Aerodynamics 257 (2025). https://doi.org/10.1016/j.jweia.2024.105992.

[3] M.A. Hasan, F. Khaled, F.T. Lombardo, Advancing tornado-like vortex (TLV) generation in straight-line wind simulators: An LES study, Journal of Wind Engineering and Industrial Aerodynamics 271 (2026). https://doi.org/10.1016/j.jweia.2026.106373.

Numerical modelling of Po Valley tornado-like-vortices using Cloud Model 1: Quantifying tornado genesis mechanisms

Michael David Hope[1], Alessio Ricci [1] & Djordje Romanic[2]

[1] University School for Advanced Studies IUSS Pavia, Italy
[2] McGill University, Montréal, Canada

E-mail: *michaeldavid.hope@iusspavia.it*

Abstract

Tornadoes represent a significant but under-represented wind hazard in the Po Valley, where historical EF-2+ (i.e. gusts over 48 $\mathrm{m\ s^{-1}}$) events have produced severe localised damage. However, the non-synoptic mechanisms governing tornado genesis and near-surface extreme wind loading in the region remain poorly constrained in both atmospheric science and wind engineering literature.

This research develops a high-resolution numerical framework to reproduce tornadic winds atop flat and realistic Po valley orography. The approach couples Cloud Model (CM) 1 (Bryan and Fritsch 2002) large-eddy simulations with realistic meso-γ scale forcing derived from Weather Research and Forecasting model simulations of selected Po Valley tornadic cases. WRF output is used to extract vertically resolved thermodynamic and kinematic profiles, which are horizontally homogenised and applied as initial conditions for CM1. CM1 v21.1 is configured with $\leq$ 60 m horizontal grid spacing and vertically stretched resolution from 25 m in the boundary layer to 275 m aloft. The model employs the Deardorff (1980) sub-grid scale turbulent kinetic energy closure scheme, Morrison et al. (2009) dual-moment explicit microphysics, semi-slip surface boundary condition(s) and fully compressible, non-hydrostatic dynamics. Convection is initiated via an ellipsoidal vertical velocity perturbation.

Preliminary simulations produce key pre-tornadic features, including a low-level mesocyclone (updraught) supported by vertically stacked negative pressure perturbations, a strong non-hydrostatic vertical pressure perturbation gradient force, and vortex tilting/stretching dynamics. A coherent boundary-layer inflow jet that conglomerates horizontal vorticity exceeds 30 – 35 $\mathrm{m\ s^{-1}}$. WRF-derived diagnostics indicate sufficient deep-layer and low-level vertical wind shear, quantified by storm-relative helicity (> $400\ \mathrm{m^2\,s^{-2}}$) consistent with significant tornadogenic regimes. The framework enables explicit quantification of near-surface wind-speed distributions, dynamic pressure perturbation gradient forces, stress tensors, and vorticity evolution. CM1 outputs will provide physically consistent flow fields for CFD-LES simulations, enabling detailed assessment of tornado-induced wind loading and supporting future regional wind-hazard evaluation.

Keywords: Tornadic wind, Cloud Model 1, Po Valley

References:

[1] Bryan, G. H., and J. M. Fritsch, 2002: A Benchmark Simulation for Moist Nonhydrostatic Numerical Models. Mon. Weather Rev., 130, 2917–2928, https://doi.org/https://doi.org/10.1175/1520-0493(2002)130%3C2917:ABSFMN%3E2.0.CO;2.

[2] Deardorff, J. W., 1980: Stratocumulus-capped mixed layers derived from a three-dimensional model. Boundary. Layer. Meteorology., 18, 495–527, https://doi.org/10.1007/BF00119502.

[3] Morrison, H., McCoy, R. B., Klein, S. A., Xie, S., Luo, Y., Avramov, A., ... & Zhang, G. 2009: Intercomparison of model simulations of mixed-phase clouds observed during the ARM Mixed-Phase Arctic Cloud Experiment. II: Multilayer cloud. Quarterly Journal of the Royal Meteorological Society, 135, 1003–1019, https://doi.org/10.1002/qj.415.

Advancing Debris Modeling for Tornadoes and Tornado Risk Assessment

Sung Min Moon [a], Franklin T. Lombardo [a] & David Bodine [b]

[a] Civil and Environmental Engineering, University of Illinois Urbana-Champaign, Urbana, IL, US)
[b] Atmospheric Sciences (University of Oklahoma, Norman, OK, US)

E-mail: lombaf@illinois.edu

Abstract
Recent efforts have focused on improving the physical realism of windborne debris modeling for tornado hazards by leveraging advances in computational fluid dynamics (CFD), high-resolution numerical simulations, and field-based damage observations. Traditional debris models have typically represented debris using a limited set of idealized object categories. New approaches integrate detailed debris inventories obtained from post-event damage surveys with high-fidelity tornado flow fields, enabling more representative characterization of debris sources, transport, and impact potential. These developments are supported by enhanced workflows for six-degree-of-freedom (6DOF) debris aerodynamics, allowing debris motion to be simulated with greater accuracy in complex tornado flows. The resulting improvements will provide more reliable predictions of debris trajectories and reveal important differences between debris transport in tornadoes versus the atmospheric boundary layer (ABL). These advances support downstream applications including tornado wind speed estimation and forensic damage assessment. Ultimately, the improved understanding of tornado-generated debris will contribute to the development of performance-based wind engineering frameworks for tornadoes that more accurately quantify risk and inform resilient structural design.

Keywords: tornado, debris, wind speed

Towards fragility curves for buildings subjected to non-synoptic like winds generated through an active-controlled multi-blade flow device

Rigoberto Morales Hernández [a], Stefano Brusco [b] Alessio Ricci [c] & Maria Pia Repetto [a]

[a] Department of Civil, Chemical and Environmental Engineering, University of Genoa, Genoa, Italy
[b] Department of Civil and Environmental Engineering, Western University, London, Canada
[c] Department of Sciences, Technologies and Society, University School for Advanced Studies IUSS, Pavia, Italy

E-mail: rigobertomorales.hernandez@edu.unige.it

For decades, the focus of wind tunnel experimentation has been synoptic winds, hence, most wind tunnel facilities are more appropriate for replicating the Atmospheric Boundary Layer (ABL). However, non-stationary wind flows, such as those generated by thunderstorm downbursts, can cause a significant amount of damage [1]. Thunderstorm downbursts, characterized by a vertical downdraft of air impinging the ground followed by radial outflows, are challenging to reproduce in traditional ABL Wind Tunnel (ABLWT) facilities. An alternative is to recreate the transient flow acceleration of the outflow front, neglecting the vertical downdraft component, adapting the ABLWT by means of a multi-blade flow device [2,3]. The present research study is part of a more extensive PhD project aimed at developing fragility curves for typical Italian low-rise buildings subjected to non-synoptic extreme wind events. This work package (WP) is focused on obtain the pressures due to outflow front flows over a low-rise building model using an active-controlled multi-blade flow device installed in the facilities of Giovanni Solari Boundary Layer Wind Tunnel at University of Genoa, Italy. The present tests are conducted in the framework of ERIES-TRANSWindS project on a model representing a masonry construction typical of the Italian urban fabric. Two building heights are tested under two exposure conditions: isolated building and urban surroundings. Uni-directional transient wind velocity profiles are obtained by moving the blades of the active grid between two previously determined profiles, executing these transitions using four different temporal scales. To investigate the effects of transient non-synoptic winds on the static pressure, measurements of the ground pressure are collected. As result, pressure coefficients over the surface of the model are obtained, as well as the transient time histories of the pressures. This information will be used as input in a Finite Element Model as a later WP of the PhD research. The primary outcome of this WP is a unique dataset of pressure measurements induced by the outflow front of downburst-like winds. The dataset provides a valuable benchmark for investigating unsteady aerodynamic effects, comparing results across different tornado and downburst simulation facilities, and validating computational fluid dynamics (CFD) models.

Keywords: downburst outflow, fragility, low-rise building, active-controlled multi-blade flow device

References:

[1] Calotescu, I., Chitez, A.-S., Birsan, M.-V., Micu, D., and Dumitrescu, A., "Assessment of Thunderstorm-Prone Areas in Romania Based on Wind Damage Occurrence and Surface Observation Data," Journal of Wind Engineering and Industrial Aerodynamics,Vol. 250, 2024, p. 105765. https://doi.org/10.1016/j.jweia.2024.105765

[2] Le, V., and Caracoglia, L., "Generation and Characterization of a Non-Stationary Flow Field in a Small-Scale Wind Tunnel Using a Multi-Blade Flow Device," Journal of Wind Engineering and Industrial Aerodynamics, Vol. 186, 2019, pp. 1–16. https://doi.org/10.1016/j.jweia.2018.12.017

[3] Yuan, Y., Yan, B., Zhou, X., Li, X., Yang, Q., Zhou, X., and Shu, Z., "An Active-Controlled Multi-Blade Facility to Generate 2-D Downburst-like Outflows in the Boundary Layer Wind Tunnel," Journal of Wind Engineering and Industrial Aerodynamics, Vol. 248, 2024, p. 105713. https://doi.org/10.1016/j.jweia.2024.105713

Turbulent Boundary Layer Height Scales in Hurricanes

Kishore R. Sathia and Marco G. Giometto
Department of Civil Engineering and Engineering Mechanics
Columbia University, New York, NY 10027, USA
Email: mg3929@columbia.edu

Abstract
Boundary layer processes drive the air–sea exchange of momentum, heat, and moisture that powers and shapes hurricanes. The boundary layer height is a critical parameter in engineering and meteorological models of hurricane wind speed, turbulence intensity, and storm strength. Existing models rely on a height scale derived with the assumption of a constant eddy viscosity, a strong simplification that limits physical accuracy. This work proposes formulae for the turbulent boundary layer height in hurricanes outside the eyewall. The proposed scalings are $u*/\beta$ for neutral stratification, and $u*/\sqrt{\beta N}$ for stable stratification, where $u*$ is the friction velocity, β is the absolute fluid vorticity and N is the Brunt-Vaisala frequency of the background stratification. These scalings are analogous to those used in the literature for neutrally and stably stratified turbulent atmospheric boundary layers. The formulae are backed by analytical derivation and validated against velocity profiles from large-eddy simulations and field observations. They are predictive to within 2.5% relative error on average and yield a good collapse of the simulated and observational velocity profiles away from the surface. The results further enable quantitative relationships between boundary layer height and other characteristic scales, including the height of maximum wind speed and the depth of the inflow layer. The proposed expressions offer a practical basis for interpreting observational data, informing mesoscale simulations, and specifying turbulent flow statistics in wind engineering and coastal resilience.

Keywords: Hurricane boundary layer, tropical cyclone, boundary layer height, turbulence, large-eddy simulation

MS8

Reliability-based Progressive Collapse Analysis of RC Frame Structures via the Global Factor Method

Luchuan Ding [a,b], **Fulvio Parisi** [a], **Xiaohui Yu** [c] & **Nian Lin** [c]

[a] Department of Structures for Engineering and Architecture, University of Naples Federico II, Via Claudio 21, 80125 Naples, Italy

[b] State Key Laboratory of Disaster Reduction in Civil Engineering & College of Civil Engineering, Tongji University, Shanghai 200092, China

[c] Guangxi Key Laboratory of Green Building Materials and Construction Industrialization, Guilin University of Technology, Guilin 541004, China

E-mail: *fulvio.parisi@unina.it*; *cqudinglc@163.com*

Abstract

Robustness can be defined as the insensitivity to initial damage in structural engineering. Structural systems need to be robust enough to withstand unforeseeable or abnormal loading, as well as to mitigate the risk of progressive or disproportionate collapse[1-2]. Structural robustness is a system property rather than a member/ cross-sectional-level property, e.g., load redistribution ability. Hence, it requires system-level or global safety evaluation. This can be achieved using nonlinear numerical or finite element analysis procedures. If the reliability of the system resistance against progressive collapse is to be evaluated, the effects of random variation of basic variables need to be accounted for. However, the use of partial safety factors is questionable for this purpose, while full probabilistic analysis is typically computationally prohibitive. The global resistance safety factor approach outlined in the *fib* Model Code[3] provides a potential alternative solution to address this problem. The global factor method (GFM) allows estimating the design value of structural resistance using a limited number of nonlinear analyses, while accounting for uncertainties in structural response at the system level and thereby conducting a global safety verification. This study introduces and further develops the GFM for progressive collapse design and assessment of reinforced concrete (RC) frame buildings under column removal scenarios. A GFM-probabilistic density evolution method-based approach is proposed to efficiently calibrate the adjustment factor for the estimated coefficient of variation of global structural resistance. Regarding two-dimensional multi-story RC frames, the adjustment factor is calibrated based on twenty-four column removal cases derived from six planar RC frame models. Subsequently, global safety factors corresponding to different target reliability levels are determined. Finally, progressive collapse safety assessment is conducted by comparing the design value of the global structural resistance with the design loads. This study reveals the potential of the improved GFM as an efficient methodology for progressive collapse design and assessment within a reliability-based framework.

Keywords: structural robustness, global factor method, system reliability, column removal scenario

References:

[1] J.M. Adam, F. Parisi, J. Sagaseta, X.Z. Lu, Research and Practice on Progressive Collapse and Robustness of Building Structures in the 21st Century, Engineering Structures. 173 (2018) 122-49.

[2] A.S. Cao, A.T. Beck. On the Quantification of Robustness and Its Thresholds, Structural Safety. 120 (2026) 102688.

[3] *fib*, *fib* Model Code for Concrete Structures 2020, V1.2 ed., Lausanne, 2024.

Data augmentation framework for black swan structural failure modes under earthquakes

Jungho Kim [b] & Taeyong Kim [b]

[a] Department of Civil and Environmental Engineering, Sejong University, Seoul, South Korea
[b] Department of Civil and Environmental Engineering, Yonsei University, Seoul, South Korea

E-mail: *tyong.kim@yonsei.ac.kr*

Abstract

Machine learning has emerged as a promising alternative to computationally expensive nonlinear structural analyses for predicting seismic responses and structural failure modes. Accurate prediction of multiple failure modes, particularly rare or black swan failure events under earthquakes, requires a high-quality and well-balanced dataset containing sufficient samples for each failure mode. In practice, however, seismic response datasets are often highly imbalanced, leading machine learning models to be biased toward dominant failure modes and resulting in poor predictive performance for rare but critical failures. While significant research has focused on developing advanced machine learning models, comparatively little attention has been paid to systematic frameworks for constructing reliable and balanced datasets for seismic failure mode prediction. To address this gap, this study proposes a data augmentation framework for constructing balanced datasets that explicitly incorporate distinct and rare structural failure modes under earthquake loading [1]. The proposed framework consists of three key steps. First, critical ground motion features (GMFs) are identified to effectively characterize earthquake time histories. Second, an adaptive algorithm is employed to estimate the probability density functions of different failure domains in the joint space of selected GMFs and structural parameters. Third, samples drawn from these probability densities are transformed into physically consistent ground motion time histories through a scaling factor optimization process. A balanced dataset is then constructed by performing nonlinear response history analyses on structural systems with parameters corresponding to the generated samples and subjecting them to the synthesized ground motions. Numerical investigations are conducted to evaluate the performance of the proposed framework by comparing deep neural network models trained on balanced and imbalanced datasets. The results demonstrate that the proposed data augmentation framework effectively mitigates dataset imbalance, enhances the representation of black swan failure modes, and significantly improves the accuracy and robustness of machine learning-based seismic failure mode prediction.

Keywords: Black swan event, Deep learning, Failure mode, Uncertainty

References:

[1] J. Kim, T. Kim, Constructing Balanced Datasets for Predicting Failure Modes in Structural Systems Under Seismic Hazards, Eng. Struct. 346 (2026) 121637.

The Value of Information of Robustness under Adversarial Actions

Leandro Iannacone [a], Alex Sixie Cao [b]

[a] Department of Building and Environmental Technology, Lund University, Lund, Sweden,
[b] School of Civil and Environmental Engineering, Nanyang Technological University, Singapore

E-mail: Leandro.iannacone@kstr.lth.se

Abstract

Robustness is a damage-limiting property of a system subject to unforeseen and abnormal loading that often lies outside the scope of typical design practices. Accidental events or deliberate malicious actions may trigger local damage that can propagate and lead to disproportionate system failure. Quantifying robustness helps devise rational preventive measures to reduce adverse effects and maintain functionality despite disruptions caused by accidental or malicious actions.

Redundancy is one possible robustness strategy, where a higher capacity of load redistribution generally results in a lower probability of system failure following an initial disruptive event. Redundancy can be quantified and visualized for a specific system in conjunction with its reliability. The so-called π–β plots [1] help visualize the likelihood that an initial attack leads to failure of the entire system. In particular, they allow comparison between a targeted attack (i.e., one aimed at maximizing disruption) and an uninformed attack (for example, one executed without knowledge of the system layout, component reliabilities, or critical elements). The goal of this presentation is to provide a method to interpret such difference in terms of a Value of Information (VoI) index for robustness. In contrast to the traditional VoI frameworks, which typically quantify the benefits of collecting information, the VoI in this context measures the potential harm resulting from an attacker gaining access to such information. This paper quantifies robustness using a newly developed robustness index [2] and integrates it into a new VoI index for adversarial settings. A case study considers a simple Daniels system subjected to different attacks, under varying assumptions regarding the attacker's strategy and available resources.

Keywords: Structural Robustness, Malicious Attacks, Value of Information

References:

[1] S. Lim, T. Kim, J. Song, System-reliability-based disaster resilience analysis: Framework and applications to structural systems, Structural Safety 96 (2022) 102202. doi:10.1016/j.strusafe.2022.102202.

[2] A. S. Cao, A. T. Beck, On the quantification of robustness and its thresholds, Structural Safety 120 (2026) 102688. doi:10.1016/j.strusafe.2026.102688.

Probabilistic Robustness Assessment of Existing RC Buildings Subjected to Debris-Flow Impact

Federica Rauseo, Ludovico Alberico Grieco, Fulvio Parisi

Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, Italy

E-mail: *federica.rauseo@unina.it*

Abstract

Existing reinforced concrete buildings—especially when designed for gravity loads only—may be particularly vulnerable to debris-flow impact, as initial localised damage can propagate through the structural system leading to disproportionate consequences. While previous studies mainly addressed the vulnerability of RC framed buildings to debris flows and progressive collapse resistance to column-loss scenarios, less attention has been paid to structural robustness to dynamic debris-flow actions. This study proposes a robustness-oriented numerical framework for existing RC frame buildings subjected to dynamic debris-flow impact. A RC framed building representative of low-rise existing buildings is investigated via three-dimensional, lumped-plasticity, structural modelling and nonlinear time-history analysis under debris-flow impact loading in OpenSees. Transient structural response, initiation of local damage in the impacted structural members and propagation throughout the structural system are explicitly simulated, allowing final damage to be evaluated. Consequence functions are defined to transform damage into economic consequences. Probabilistic simulation is thus used to estimate a robustness indicator, accounting for uncertainty in both material and geometric properties, capacity models, and loads. Sensitivity of the probabilistic robustness indicator is also evaluated over a range of debris-flow parameters, delineating the worst conditions for building protection measures. In this way, the study moves from a vulnerability-based description of debris-flow effects toward a threat-dependent robustness assessment framework for existing RC buildings. The analyses show that local impact-induced damage associated with some debris-flow scenarios may significantly propagate within the structural system, revealing limited robustness against these natural hazards.

Keywords: structural robustness, reinforced concrete framed buildings, debris-flow impact, nonlinear dynamic analysis

Experimental Investigation of External Near-Surface Mounted Steel Wire Wrapping for Shear Strengthening of Reinforced Concrete Beams

Mohamed Ghala [a,b], Galal Elsamak [b], Rania Sira [b], Rania Sira [c] & Ashraf Ashour [a]

[a] Faculty of Engineering & Digital Technologies, University of Bradford, Bradford BD71DP, UK,

[b] Civil Engineering Department, Faculty of Engineering, Kafrelsheikh University, Kafrelsheikh, Egypt,

[c] Civil Engineering Department, Faculty of Engineering, Jerash University, 26150, Jerash, Jordan,

E-mail: m.s.a.e.g.ghala@bradford.ac.uk

Abstract

Shear-deficient reinforced concrete (RC) beams are susceptible to sudden brittle failure, yet the use of near-surface-mounted (NSM) steel wires as external wrapping systems for shear strengthening has received limited attention. This study experimentally investigates the effectiveness of innovative external NSM steel wire wrapping configurations for enhancing the shear performance of RC beams. Several strengthening schemes were examined, including U-wrapped, fully wrapped vertical, fully wrapped inclined, and cross-pattern arrangements with steel wire inclinations of 45°, 60°, and 90°.

The results demonstrated substantial improvements in shear behavior, load-carrying capacity, stiffness, and energy absorption compared with an unstrengthened control beam. Among the tested configurations, the full cross-pattern wrapping system with four NSM steel strips inclined at 45° achieved the best performance, increasing the ultimate load capacity by 91%, stiffness by 152%, and energy absorption by 436%. The findings confirm that external NSM steel wire wrapping is an effective and practical technique for strengthening shear-deficient RC beams and provide valuable experimental evidence for future design applications.

Keywords: Shear Strengthening, Near-Surface Mounted Steel Wires, External Wrapping.

References:

[1] C. Jiang, W. Xiong, Y. Fu, J. Ye, Experimental investigation on shear performance of RC T-beams strengthened with hybrid bonded CFRP strips, Eng Fail Anal 167 (2025) 109080. https://doi.org/10.1016/j.engfailanal.2024.109080.

[2] M. Elkafrawy, S. Fayed, B. ahmed Ramadan, Strengthening of RC beams defected in shear using external bonded ribs made of aluminum tube sandwich filled with strain hardening cementitious composites, Case Studies in Construction Materials 21 (2024) e03998. https://doi.org/10.1016/j.cscm.2024.e03998.

[3] E. Rossi, N. Randl, Interaction between F/TRC shear strengthening and steel stirrups: Experimental observations on real-scale RC T-beams, Eng Struct 325 (2025) 119401. https://doi.org/10.1016/j.engstruct.2024.119401.

MS9

Mechanically Admissible Quantum and Classical Kernel Surrogates for Structural Capacity Domains

Salvatore Sessa[a] & Luciano Rosati[a]

[a] Dep. of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy

E-mail: salvatore.sessa2@unina.it

Abstract

Structural capacity checks of reinforced concrete beam sections subject to axial force and biaxial bending can be formulated as a binary classification problem in a low-dimensional generalized stress space. Machine learning classifiers, including support vector machines with classical or quantum-inspired kernels, provide accurate surrogate models of such capacity domains when trained on numerically generated data. Nevertheless, unconstrained learning often leads to decision boundaries that violate fundamental mechanical requirements, such as convexity, compactness, and closure, which are essential for admissible ultimate capacity domains and for safety-critical verification.

This contribution presents a unified framework for the construction of mechanically consistent surrogates, applicable to polynomial kernels. The approach enforces convexity and compactness analytically rather than through heuristic regularization or post hoc corrections. Convexification is achieved by imposing positive semi-definiteness on the quadratic components of the decision function, while coercivity ensures bounded and closed capacity domains. The resulting classifiers are interpretable, mechanically consistent, and suitable for engineering practice.

Numerical results on reinforced concrete beam sections with different geometric and reinforcement layouts show that mechanically admissible kernels may exhibit slightly reduced global accuracy compared to unconstrained counterparts, but systematically improve safety-critical performance by controlling false-positive misclassifications near the capacity boundary. The proposed framework highlights how physical admissibility can be embedded directly into machine learning models, bridging classical and quantum kernel methods for structural mechanics applications.

Keywords: machine learning, structural capacity, convexity, kernel methods

References:

[1] S. Sessa, L. Rosati, Quantum computing for capacity checks of reinforced concrete sections, Eng. Appl. Artif. Intell. 168, 113970 (2026).

[2] S. Sessa, L. Rosati, Convex physics-informed kernel for machine learning in the ultimate capacity assessment of beam sections, Comp. & Struct. (2026).

Reduced-Dataset Machine Learning for Blast Damage Assessment of RC Columns: A Multi-Step Combination Method

Yeeun Kim [a], Subin Kim [a] & Jiuk Shin [a]

[a] Department of Architectural Engineering, Gyeongsang National University, Jinju, South Korea

E-mail: jiukshin@gnu.ac.kr

Abstract

Blast-induced damage to reinforced concrete (RC) columns can lead to progressive collapse of building structures, making rapid and accurate blast damage assessment essential. However, conventional field tests and finite element (FE) simulations for evaluating blast resistance are costly and time-consuming. Although machine learning (ML) approaches have been widely adopted to overcome these limitations, existing ML models typically require large datasets, which demands significant computational effort and data collection resources. This study proposes a novel ML combination technique that achieves high prediction accuracy using a substantially reduced dataset. A multi-step ML model was developed by integrating two distinct classifiers: a failure mode (FM) model that identifies column failure types (shear or flexure) from simple structural details, and a blast resistance evaluation (BRE) model that predicts blast-induced damage levels (D1 to D5) based on ductility-based limits defined in ASCE 59-22. A learning dataset of 703 data points was generated from well-validated LS-DYNA FE simulations, but the proposed combination method (CM) model was trained on only 200 data points — a 71.5% reduction compared to the conventional general method (GM) model. The CM model employs individualized binary classifiers for each damage level and integrates four combination strategies. Among them, the combined prediction method (Method-4), which merges sequential prediction with maximum positive probability selection, achieved the highest average accuracy of 77.77%. Compared to the GM model trained on the full dataset, Method-4 improved precision and recall by 16.2% and 21.9%, respectively, and enhanced the average prediction performance across all damage levels by 14.3%. These results demonstrate that the proposed approach can significantly reduce data dependency in ML-based blast damage assessment while maintaining high predictive reliability.

Keywords: Machine learning, Reduced dataset, Blast damage assessment, Reinforced concrete column

References:

[1] Kim, Y., Lee, K., Shin, J. (2026). Reduced dataset-based machine learning model for blast damage assessment of reinforced concrete columns. Engineering Structures, 353, 122262.

[2] Kim, Y., Lee, K., Shin, J. (2025). Ductility and residual strength-based blast resistance evaluation of RC columns with various structural details. Structures, 77, 109179.

[3] American Society of Civil Engineers (ASCE). (2022). Blast Protection of Buildings. ASCE/SEI 59-22, Reston, VA.

Blast Performance Evaluation of Reinforced Concrete Columns Using Conditional Generative Adversarial Networks

Haewon Kang [a], Eunbin Son [a] & Jiuk Shin [a]

[a] Department of Architectural Engineering, Gyeongsang National University, Jinju, South Korea

E-mail: jiukshin@gnu.ac.kr

Abstract

Evaluating the blast resistance of reinforced concrete (RC) structures is a critical challenge for defense and infrastructure protection. Conventional finite element method (FEM) simulations provide high-fidelity results but are computationally expensive and time-consuming, limiting their applicability for real-time assessment. While machine learning approaches have been proposed as efficient alternatives, they have largely been confined to predicting single scalar indicators such as maximum displacement or residual stiffness [1], failing to capture the spatial distribution of damage or the associated failure modes. To address these limitations, this study proposes a deep learning framework based on a conditional generative adversarial network (cGAN). Trained on FEM simulation data generated under diverse blast loading conditions, the model takes blast loading parameters as input and simultaneously predicts the full-field damage distribution and concrete failure regions of RC columns as spatial image outputs. The framework achieves accuracy comparable to FEM simulations while drastically reducing computation time, and demonstrates stable generalization to unseen loading conditions [2]. By directly visualizing damage locations and failure modes [3], the proposed approach enables more comprehensive blast performance evaluation and holds strong potential for real-time structural safety assessment.

Keywords: Conditional GAN, reinforced concrete, blast, damage distribution

References:

[1] M.K. Almustafa, M.L. Nehdi, Machine Learning Model for Predicting Structural Response of RC Slabs Exposed to Blast Loading, Eng. Struct. 229 (2021) 111721.

[2] Z. Li, Y. Chen, L. Yan, Z. Liang, Deep Learning-Based Rapid Damage Assessment of RC Columns under Blast Loading, Eng. Struct. 271 (2022) 114949.

[3] K. Lin, Y. Li, X. Lu, H. Gu, Damage Scenario Prediction for Concrete Bridge Columns Using Deep Generative Networks, Struct. Control Health Monit. 2024 (2024) 5526537.

Generative Model for Predicting Nonlinear Backbone curves of Reinforced Concrete Columns

Youngmin Song [a], **Taehyeon Kim** [a] **& Jiuk Shin** [a]

[a] Dept. of Architectural Engineering, Gyeongsang National University, Jinju-si, Republic of Korea

E-mail: jiukshin@gnu.ac.kr

Abstract

Seismically deficient reinforced concrete (RC) columns have caused significant structural collapses in past earthquakes. Backbone curves, which characterize the nonlinear lateral resistance of RC columns, are essential for seismic performance assessment - particularly in nonlinear static (pushover) and dynamic analyses used in performance-based earthquake engineering frameworks. However, conventional analytical and numerical methods are limited by computational cost and modeling complexity. Although machine learning-based approaches have been proposed to predict individual backbone curve parameters, they are limited in directly generating the full continuous curve shape.

This study proposes a conditional generative model that directly produces backbone curves of RC columns from basic structural design variables, without requiring failure mode classification as an auxiliary input. The framework combines a Variational Autoencoder (VAE) with Generative Adversarial Network (GAN) adversarial learning, which enforces generation quality through competition between a Generator and Discriminator. Two key enhancements are introduced: (1) a mismatched condition discriminator loss term [1], which explicitly trains the Discriminator to distinguish condition-output mismatches, improving the consistency between input design variables and generated curve shapes; and (2) Hilbert curve-based spatial encoding [2], which maps 1D backbone sequences onto a 2D spatial representation, enabling convolutional networks to simultaneously capture local continuity and global shape structure across the full deformation range. Conditional input variables were selected via minimum-redundancy maximum-relevance (mRMR) [3] analysis, and the model was trained on 182 RC column specimens. On the test dataset, the proposed model achieved R = 0.98, MAE = 0.02 and MAPE = 9.45 %, outperforming comparative models across both flexure and shear-governed failure modes.

The proposed model integrates directly into seismic assessment workflows, replacing empirical or FE-based backbone curve definitions for rapid nonlinear characterization.

Keywords: reinforced concrete columns, backbone curve, conditional generative model

References:

[1] S. Reed, Z. Akata, X. Yan, L. Logeswaran, B. Schiele, H. Lee, Generative Adversarial Text to Image Synthesis, in: Proc. IEEE Conf. Comput. Vis. Pattern Recognit., 2016, pp. 1060–1069.

[2] N.R.B.S. Loka, M. Kavitha, T. Kurita, Hilbert Vector Convolutional Neural Network: 2D Neural Network on 1D Data, in: Artificial Neural Networks and Machine Learning – ICANN 2019: Theoretical Neural Computation, 11727 (2019) 458–470.

[3] H. Peng, F. Long, C. Ding, Feature Selection Based on Mutual Information Criteria of Max-Dependency, Max-Relevance, and Min-Redundancy, TPAMI 27 (2005) 1226–1238.

Machine Learning Surrogate Models for Stochastic Structural Mechanics with Spatially Random Material Properties

Neander Mendes [a], **Lineu Pedroso** [b]

[a] Department of Agricultural Engineering, Universidade Estadual de Goiás (UEG), Anápolis, Goiás, Brazil
[b] Department of Civil and Environmental Engineering, Universidade de Brasília (UnB), Brasília, DF, Brazil

E-mail: neander.mendes@ueg.br

Abstract

High-fidelity finite element models are fundamental in structural mechanics for accurately predicting the dynamic response of complex civil structures. When spatial variability of material properties is explicitly considered, stochastic simulations provide a physically consistent framework for uncertainty quantification; however, they become computationally intensive in large-scale parametric studies, reliability assessment, or repeated simulations required in model-updating environments.

This study presents a machine learning surrogate modeling framework that integrates physics-based finite element simulations with data-driven prediction tools. Spatial variability is represented through continuous random fields embedded into a structural formulation under dynamic loading. A stochastic simulation campaign generates response data, including displacements and stress measures at mechanically relevant locations. The methodology is illustrated through a gravity dam structure [1] representative of a large-scale concrete system, while remaining applicable to broader classes of civil structures. Building upon established surrogate modeling strategies, the proposed framework emphasizes the integration of spatially variable random fields with machine learning models within a unified and scalable workflow, enabling scalable stochastic analysis while preserving physical interpretability. Tree-based machine learning algorithms are trained and evaluated as surrogate models, with emphasis on robustness and generalization. The surrogate models accurately approximate the stochastic input–response mapping obtained from the finite element simulations, preserving key mechanical trends captured by the underlying physics-based formulation while significantly reducing computational demand, with negligible loss of accuracy in key response metrics, including displacement responses and stress-based indicators at critical structural locations, while maintaining high predictive accuracy in the surrogate modeling stage.

Beyond computational efficiency, the proposed framework enables identification of influential spatial parameters through model-based feature importance analysis, supporting probabilistic structural assessment and reliability-oriented decision-making. The approach establishes a foundation for digital twin implementations in structural mechanics, where stochastic models can be continuously updated and employed for predictive assessment within data-integrated environments.

Keywords: stochastic finite element methods; surrogate modeling; uncertainty quantification; machine learning for structural mechanics

Reference:

[1] N.B. Mendes, L.J. Pedroso, Structural verification of a gravity dam under seismic action using machine learning, Computers and Structures 321 (2026) 108077.

Bayesian-Driven Optimization of Recoverable Strain in Compliant Auxetic Cementitious Composites for Energy Harvesting Applications

Jinbao Xie [a], **Branko Šavija** [a]

[a] Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands

E-mail: J.Xie-1@tudelft.nl

Abstract

The higher deformability-induced strain energy of auxetic cementitious cellular composites (ACCCs) offers prospects for energy harvesting by using flexible piezoelectric materials. However, the intrinsic brittleness of cementitious materials and the complex coupling between auxetic geometry and damage evolution hinder the efficient design of ACCC energy harvesters. This study proposes a novel learning-driven design framework that, for the first time, integrates a physics-based energy harvesting model with Bayesian Optimization (BO) to directly optimize the recoverable hinge-like recoverable strain capacity of ACCCs for enhanced electrical output. The optimization maximizes the voltage generated by piezoelectric materials bonded at hinge regions, while using constraints to prevent splitting failure and non-auxetic behavior under compression. The energy harvesting model combines the concrete damage plasticity (CDP) model for pre-compression damage with a secondary elastic model for cyclic loading, enabling prediction of recoverable strain in generalized ACCC geometries. It accounts for their deformed geometries for energy harvesting, which are reconstructed using an improved node-order tracking algorithm. The learning-driven approach proved far more efficient than random generation in identifying optimal ACCC configurations. Experimental validation of the optimized design achieved a peak-to-peak voltage of nearly 15.0 V per cycle, about 2.7 times higher than a reference design. The evolution of geometric features and mechanical performance during BO iterations was investigated, which elucidates the improvement in recoverable hinge-like strain capacity and provides guidance for design optimization. This study presents a learning-driven approach to designing enhanced compliant auxetic cementitious energy harvesters, supporting the advancement of sustainable and smart infrastructure.

Keywords: Energy harvesting, Auxetic cementitious cellular composites, Recoverable strain capacity, Bayesian Optimization

A regression model for regional-scale anomaly characterization in masonry bridges based on spaceborne radar measurements

Wael Alahmad [a], **Said Quqa** [b] & **Cristina Gentilini** [a]

[a] Department of Architecture, University of Bologna, Bologna, Italy

[b] Department of Civil, Chemical, Environmental, and Materials Engineering, University of Bologna, Bologna, Italy

E-mail: cristina.gentilini@unibo.it

Abstract

This study proposes a population-based structural health monitoring framework for the detection and characterization of anomalies in historical masonry arch bridges using satellite differential interferometric synthetic aperture radar (DInSAR) data and environmental measurements. The methodology integrates feature extraction from displacement time series and environmental variables with a domain adaptation strategy based on subspace alignment, enabling cross-bridge harmonization of statistical descriptors [1,2]. The core contribution of the work lies in a regression-based learning model designed to provide physically interpretable anomaly indicators for all bridges in the monitored population. A bidirectional long short-term memory (BiLSTM) neural network is trained exclusively on synthetic data generated through a simplified parametric bridge model calibrated with real measurements. The proposed regressor directly estimates continuous and engineering-relevant quantities: (*i*) the intensity of pier settlement or uplift and (*ii*) the spatial extent of the affected region. The bidirectional architecture exploits full temporal context within short analysis windows, enabling discrimination between environmentally driven cyclic behavior and persistent anomalies. By combining simulation-to-real transfer learning with a dual-output regression strategy, the framework overcomes the scarcity of labeled anomaly data while preserving interpretability in the original displacement domain. Validation on eight historical railway bridges in Liguria, Italy, demonstrates the capability of the model to automatically identify and quantitatively characterize settlement patterns, showing its effectiveness in supporting a scalable, non-invasive monitoring of civil infrastructures.

Keywords: masonry arch bridge, satellite measurement, transfer learning, population-based structural health monitoring

References:

[1] S. Quqa, O. Lasri, G. Delo, P.F. Giordano, C. Surace, A. Marzani, M.P. Limongelli, Regional-Scale Bridge Health Monitoring: Survey of Current Methods and Roadmap for Future Opportunities Under Changing Climate, Struct. Health Monit. 24 (2025) 14759217241310525.

[2] W. Alahmad, S. Quqa, F. Ubertini, C. Gentilini, Anomaly Identification in Historical Modular Structures Using Satellite Data: Methodology and Application to Portico di San Luca, Bologna. J. Build. Eng. 701 (2025) 114893.

Multi-Scale Structural Graph Neural Networks for Efficient Prediction of Structural Responses

Qilin Li [a], Yanda Shao [a], Ling Li [a] & Hong Hao [b,c]

[a] School of Electrical Engineering, Computing and Mathematical Sciences, Curtin University, Perth, Australia
[b] Earthquake Engineering Research & Test Centre, Guangzhou University, Guangzhou, China
[c] Centre for Infrastructural Monitoring and Protection, School of Civil and Mechanical Engineering, Curtin University, Perth, Australia

E-mail: qilin.li@curtin.edu.au

Abstract

Finite element modelling (FEM) is widely used to simulate structural responses under impact loads, but its high computational demand limits its application for large-scale, fine-grained models. Graph Neural Networks (GNNs) offer a promising surrogate modelling approach [1, 2]; however, the conventional one-to-one mapping from finite elements to graph nodes still suffers from significant memory and scalability constraints. This study introduces a multi-scale structural GNN framework that overcomes these limitations through hierarchical graph representations at multiple abstraction levels: element-level nodes, structural component-level nodes, and object-level nodes (e.g., vehicle and road barrier). By conducting message passing at higher abstraction levels, the framework reduces memory usage and computational time while enhancing the modelling of higher-level structural interactions. The proposed method integrates information across scales, enabling efficient simulations without sacrificing accuracy in predicting both local and global structural behaviours. Performance is evaluated against high-fidelity FEM simulations of concrete structures subjected to impact loading. Results show substantial reductions in computation time and memory consumption while maintaining strong predictive accuracy across key response metrics. This work demonstrates the potential of multi-scale GNNs to provide rapid and scalable structural response simulations, offering a practical tool for impact engineering applications where conventional FEM is computationally prohibitive.

Keywords: Graph Neural Networks, Multi-Scale Modelling, Structural Response Prediction

References:

[1] Li, Q., Wang, Z., Li, L., Hao, H., Chen, W. and Shao, Y., 2023. Machine learning prediction of structural dynamic responses using graph neural networks. Computers & Structures, 289, p.107188

[2] Li, Q., Huang, Z., Shao, Y., Li, L., Chen, W. and Hao, H., 2025. Dynamic graph-based approach for prediction of spatiotemporal response of RC structure to impact loads. *Computers & Structures*, *316*, p.107861.

Explainable Machine Learning for Corrosion Degradation Assessment of Steel Port Structures Using Atmospheric Sensor Data

Mohamed El Amine Ben Seghier[a], **Enobong Felix Daniel[a]**, **Haijie Tong[a]**, **Yan Miao**, **& Daniel Höche[a]**

[a] Institute of Surface Science, Helmholtz, -Zentrum Hereon, Geesthacht, Germany

E-mail: Mohamed.ben@hereon.de

Abstract

Atmospheric corrosion of steel structures in port environments represents a critical durability challenge for transportation infrastructure, leading to substantial maintenance and repair costs each year. The aggressive marine atmosphere that is characterized by high humidity, temperature fluctuations, rainfall, and saline exposure, accelerates electrochemical corrosion processes, making reliable prediction of degradation levels particularly challenging. This study investigates a data-driven and explainable machine learning framework for predicting corrosion degradation in steel port structures using long-term atmospheric monitoring data. Corrosion measurements obtained from atmospheric corrosion monitor sensors, previously deployed at the Port of Kiel, Germany, are combined with environmental parameters such as relative humidity, temperature, rainfall, and other climatic indicators to analyze their influence on corrosion current intensity. Several gradient boosting algorithms, including Extreme Gradient Boosting (XGBoost), Gradient Boosting Regression Trees (GBRT), and Categorial Boosting (CatBoost), are implemented to develop predictive models capable of estimating corrosion levels under varying environmental conditions. To ensure model transparency and physical interpretability, SHAP (SHapley Additive exPlanations) is employed to interpret the predictions and quantify the relative influence of environmental variables on corrosion progression. The proposed framework not only achieves accurate prediction of corrosion current density but also provides interpretable insights into the environmental drivers of structural degradation. Such explainable models can support structural health monitoring and maintenance planning by enabling early identification of high-risk corrosion conditions in port infrastructure. The results demonstrate the potential of integrating sensor data, machine learning, and explainable AI to assist engineers in proactive maintenance decision-making for steel maritime structures.

Keywords: Atmospheric corrosion, steel structures, sensors, explainable AI

Insights on AI-driven algorithms for automated clustering of persistent scatterer-based interferometry

Sandropio Scoccola [a], **Tony Fierro [a]** & **Antonio Sandoli[a]**

[a] Department of Biosciences and Territory, University of Molise, Campobasso, Italy

E-mail: antonio.sandoli@unimol.it

Abstract

Interferometric Synthetic Aperture Radar (InSAR) data theoretically represents an invaluable tool to carry out long-term serviceability displacements monitoring of ground surface, structures and infrastructures. However, its use in civil engineering problems is still debated, such as spatial and temporal clustering of the data [1-3] representing the way of aligning displacement time-series coming from different orbits acquired in different time. The Point Scatterers interferometry (PS) clustering, in fact, depends upon several parameters related to (different) travelling orbits of ascending and descending satellites, coherence of the measures, points density, displacement velocities, etc. Basically, the aggregation criteria of the PSs - and clusters dimensions selection - is traditionally based on engineering judgments, whose effectiveness may be affected by the knowledge level of the operators, and different approaches are available in the technical literature. To overcome these limitations, deep learning clustering algorithms represent a prominent tool for generating automated PSs aggregation to monitor areas or structures and infrastructures observed via InSAR data [2]. In this paper, exiting neural network algorithms are tested and trained to generate automated clusters for monitoring urban systems and ground surface from a civil engineering perspective. With the aim of generating automated clusters, the role of different parameters was investigated (displacement velocity; PS position; coherence) with application to real-world case studies. The results obtained from the different analyses have been compared in terms of statistical reliability and of displacement time-series measures with the scope of defining a comprehensive analysis of deformation patterns based on AI-driven clustering.

Keywords: SAR, Monitoring, deep learning, clustering.

References:

[1] Sandoli A, Petracca E, Rainieri C, Fabbrocino G. Operation of interferometric SBAS-DInSAR data for remote structural monitoring of existing bridges. Journal of Bridge Engineering. 2024 Nov 1;29(11):04024085.

[2] Alonso-Díaz, A., Solla, M., Perissin, D., & Sousa, J. (2025). Unsupervised machine learning for clustering and analyzing InSAR-derived ground deformation: insights from X-and C-band. European Journal of Remote Sensing, 58(1), 2564158.

[3] G.R. Mettam, L.B. Adams, How to Prepare an Electronic Version of Your Article, in: B.S. Jones, R.Z. Smith (Eds.), Introduction to the Electronic Age, E-Publishing Inc., New York, 2009, pp. 281–304.

ML-enabled forward models of complex materials applications

Lori Graham-Brady [a], Ashwini Gupta [a] & Indrashish Saha [a]

[a] Johns Hopkins University (Hopkins Extreme Materials Institute, Johns Hopkins University, Baltimore MD, USA)

E-mail: lori@jhu.edu

Abstract

Machine learning and AI-driven methods are transforming how materials are evaluated, offering a rapid and scalable alternative to traditional physics-based modeling. While these approaches can sacrifice some accuracy and interpretability, they are increasingly effective for identifying promising material microstructures for further investigation. Their utility is amplified by advances in high-throughput experimental platforms, which generate large, statistically meaningful datasets that enable data-driven discovery. Similar trade-offs arise in high- throughput experimentation itself, where capturing complete physical detail may be less critical than efficiently detecting performance trends across material systems. This talk presents recent developments within the AI for Materials Design (AIMD) facility at Johns Hopkins, focusing on the integration of machine learning with automated, high-throughput experimentation. Emphasis is placed on the challenges of evaluating materials under extreme conditions, including high temperature, high strain rate, and high pressure, where both experimental and modeling uncertainties are amplified. We discuss how machine learning models can be used not only for screening and optimization, but also for guiding experimental design and decision-making within closed-loop frameworks.

Keywords: Machine Learning, AI-driven Design, High-throughput Experiments, Materials Optimization

Real-Time Reconstruction of Urban Flows via GAVI and SHRED

Josep Maria Duró [a], Arnau Miró [a,b], Benet Eiximeno [c], J. Nathan Kutz[d], Oriol Lehmkuhl[b], Ivette Rodríguez [a]

[a] Universitat Politècnica de Catalunya (Spain)
[b] Barcelona Supercomputing Center (Spain)
[c] NVIDIA (Spain)
[d] University of Washington (USA)

E-mail: arnau.miro@upc.edu

Abstract

Urban areas are increasingly affected by heat stress and Urban Heat Island effects driven by the progressive densification of cities. Predicting airflow patterns and scalar transport within complex city geometries is essential to support mitigation strategies, urban planning, and the development of operational digital twins. High-fidelity computational fluid dynamics approaches [1] provide accurate representations of turbulent urban flows, yet their computational cost limits their applicability for real-time prediction, uncertainty quantification, and parametric studies. This work presents a data-driven reduced-order modeling framework designed to enable fast and reliable reconstruction of urban flow fields from sparse sensor measurements. The proposed methodology combines Geometry-Agnostic Variational Autoencoders (GAVI) [2] with Shallow Recurrent Decoder Networks (SHRED) [3] into a unified architecture. GAVI is employed to extract a compact latent representation from high-resolution LES datasets at different wind angles, capturing the dominant flow dynamics. SHRED is subsequently trained as a time-aware decoder capable of reconstructing the latent dynamics using only a limited number of sensor signals. Results show that the coupled GAVI–SHRED model accurately reconstructs instantaneous velocity fields and turbulence statistics from extremely sparse probe data. These findings highlight the potential of compressive learning strategies for real-time urban flow prediction and data assimilation from meteorological stations.

Keywords: reduced-order modeling, latent space learning, sparse reconstruction, urban flows

References:

[1] Teng, M., Duró Diaz, J. M., Mestres, E., Muela Castro, J., Lehmkuhl, O., & Rodriguez, I. (2025). Atmospheric boundary layer over urban roughness: Validation of large-eddy simulation. Physics of Fluids, 37(6).

[2] Eiximeno, B., Miró, A., Kutz, J. N., Rodriguez, I., & Lehmkuhl, O. (2025). On the integration of geometry agnostic variational-autoencoders into large-scale SVD based models. Computers & Fluids, 106797.

[3] Gao, M. L., Williams, J. P., & Kutz, J. N. (2025). Sparse identification of nonlinear dynamics and koopman operators with shallow recurrent decoder networks. arXiv preprint arXiv:2501.13329.

Model-Driven Machine Learning for Efficient Seismic Damage Assessment of Industrial Non-Structural Components

Gianluca Quinci [a] **& Cristoforo Demartino** [b]

[a] Department of Civil, Computer Science and Aeronautical Technologies Engineering, Roma Tre University, Rome, Italy
[b] Department of Architecture, Roma Tre University, Rome, Italy

E-mail: *gianluca.quinci@uniroma3.it*

Abstract

The seismic performance of industrial facilities is often governed by equipment and other non-structural components (NSCs), whose failure may cause significant economic losses, interruption of operation, and potentially hazardous consequences. Direct probabilistic assessment of these components generally requires large suites of nonlinear dynamic analyses and can therefore become computationally demanding when ground-motion variability and component vulnerability are explicitly represented. This study presents a model-driven machine-learning framework aimed at accelerating the seismic damage assessment of industrial NSCs while retaining the mechanics of the coupled structure-equipment system. A computationally efficient finite-element model is first developed to reproduce the relevant dynamic response of the primary structure and its interaction with the equipment. The model is subjected to a suite of natural, hazard-consistent earthquake records to generate a simulation database containing ground-motion descriptors, structural response quantities, and component demand and capacity information. Intensity- and duration-related measures are considered together with mechanics-based response features, and dimensionality reduction is used to identify the variables that are most informative for damage classification. The selected features are then used to train an artificial neural-network surrogate for predicting limit-state exceedance of the industrial component. Its performance is evaluated against direct numerical assessment and conventional fragility-based procedures. The results show that the surrogate reproduces the main damage trends obtained from finite-element simulations while enabling rapid evaluation over large probabilistic samples, thereby substantially reducing the computational burden associated with repeated response-history analysis. The proposed framework demonstrates how efficient structural modelling and machine learning can be integrated within a risk-oriented workflow for industrial equipment. Beyond the specific case study, the approach provides a basis for rapid vulnerability screening, uncertainty propagation, and future extensions toward multi-component and system-level seismic risk assessment of critical facilities.

Keywords: Machine learning, Non-structural components, Industrial equipment, Seismic damage assessment, Artificial neural networks, Finite-element modelling

References:

[1] Quinci, G., Nardin, C., Paolacci, F., Bursi, O.S. (2023). Modelling of non-structural components of an industrial multi-storey frame for seismic risk assessment. Bulletin of Earthquake Engineering, 21, 6065-6089. https://doi.org/10.1007/s10518-023-01753-4.

[2] Quinci, G., Paolacci, F., Fragiadakis, M., Bursi, O.S. (2025). A machine learning framework for seismic risk assessment of industrial equipment. Reliability Engineering & System Safety, 254, 110606. https://doi.org/10.1016/j.ress.2024.110606.

MS10

Bifurcations in the lateral thermal buckling of subsea pipelines

D. Liu, G.H.M. van der Heijden

Department of Civil, Environmental and Geomatic Engineering, University College London, London WC1E 6BT, UK

Abstract

Subsea pipelines are required to operate under high-temperature and high-pressure conditions, which may lead to excessive axial compressive forces and possible buckling of the pipeline. Tem- perature distributions in the pipe are usually not uniform. We develop a geometrically exact rod model, hence with nonlinear coupling between axial and lateral displacement, for the study of lateral thermal pipeline buckling with inclusion of the effect of non-uniform temperature distribution. We find that buckling may be induced under increasing temperature gradient. Buckling under increasing temperature is generally described by a subcritical bifurcation. We also consider lateral buckling under non-monotonic pipe-soil interaction as a result of accu- mulated soil berms in front of the pipe, effectively forming a trench. In the absence of axial resistance the pipeline is under a dead compressive load and we identify a critical Maxwell point marking a phase transition to a periodic buckling pattern with the pipeline bouncing between the trench walls. Associated with this critical point is shock sensitivity: solutions are highly sensitive to small (finite) perturbations. Under increasing axial resistance the shock sensitivity gradually diminishes. We quantify the shock sensitivity by computing energy barriers as a function of the axial soil resistance.

Localisation of Deformation in Metallic Kirigami

Amanpreet Singh [a], Marcelo A. Dias[b] & Martin G. Walker[a]

[a] Department of Engineering, Durham University, Durham, DH1 3LE, UK
[b] Institute for Infrastructure and Environment, School of Engineering, University of Edinburgh, EH9 3FB, UK

E-mail: martin.g.walker@durham.ac.uk

Abstract

Kirigami-based metamaterials and metastructures have gained considerable attention for their unique deformation characteristics, which are controlled by the imposed cut pattern. For uniform cut patterns in initially flat elastic materials under quasi-static loading, deformation is observed to occur uniformly. However, sequential deformation has been obtained through the introduction of global curvature [1]. By using plastically deforming materials, such as metals, sequential opening is also observed, starting from the weakest region [2]. In this work we show how the introduction of plasticity introduces a propagating instability phenomenon which causes deformation to switch from uniform to sequential. We also show how the deformation sequence is influenced by strain rate using a combination of experiments, finite element analysis, and semi-analytical calculations. We identify a critical impact velocity beyond which deformation initially localizes at the impact end and propagates towards the supported end. Finally, we investigate the behaviour of a metallic kirigami sheet with a uniform cut pattern repeated in orthogonal directions, where an unexpected localisation phenomenon occurs.

Keywords: kirigami, mechanics, plasticity, impact

References:

[1] A. Rafsanjani, L. Jin, B. Deng, K. Bertoldi, Propagation of Pop Ups in Kirigami Shells, Proceedings of the National Academy of Sciences 116 (17) (2019) 8200–8205.

[2] S. Khalilzadehtabrizi, I. Mohagheghian, M. G. Walker, Analysis and Design of Kirigami-based Metallic Energy-Dissipating systems, Thin-Walled Structures, 212 (2025), 113127

Tailored Lattices for Energy Absorption

Yuhang Liu [a], Anton Köllner [a], Andrew T. M. Phillips [a] & M. Ahmer Wadee [a]

[a] Department of Civil and Environmental Engineering, Imperial College London, London, United Kingdom

E-mail: yuhang.liu24@imperial.ac.uk

Abstract

Lattice structures are commonly employed as microstructural configurations in the design of mechanical metamaterials. Metamaterials have extraordinary properties that are essentially determined by their structural arrangement, as opposed to the properties of the constituent materials, and enable broad applications across multidisciplinary fields. In the present work, the focus is on energy absorption applications. To address the incompatibility between high strength and a broad stress plateau in conventional energy-absorbing materials [1], as well as the permanent plastic deformation after mobilisation, the current work proposes a systematic geometry manipulation strategy for designing elastic lattices with enhanced energy absorption and reusability. An analytical framework, based on rigid link-spring models and potential energy principles, is established in conjunction with generalised path following techniques [2] to capture the entire stability landscape of the underlying lattice unit cells and assemblies, from which favourable equilibrium responses are selected according to functional requirements. Key locations are identified where the local stiffnesses need to be modified through investigating critical eigenvectors, and geometry manipulation techniques, including global mode seeding and local stiffness tracing, are then implemented to drive the mechanical behaviour towards the target response. Numerical examples are presented where the designed structures, based on the analytical methodology, are tested within the commercial finite element code ABAQUS to determine the validity of the proposed strategy. The results provide a rational mechanistic insight into how the metamaterial geometry governs the macroscopic mechanical behaviour of lattices, offering a systematic pathway for designing lattices with improved energy absorption performance.

Keywords: Lattice structures, Metamaterials, Stability, Nonlinear buckling

References:

[1] A. Bekele, M. A. Wadee, A. T. M. Phillips, Enhancing Energy Absorption Through Sequential Instabilities in Mechanical Metamaterials, R. Soc. Open Sci., 10 (2023) 230762.

[2] A. Köllner, N. Lüer, A Path-Following Approach for Quasi-Static Structural and Material Instability Phenomena, Comput. Meth. Appl. Mech. Eng., 436(2025) 117704.

Estimating Imperfection Sensitivity

Simon D. Guest

Department of Engineering, University of Cambridge, UK

Email: sdg@eng.cam.ac.uk

Abstract

The presentation will describe new work that aims to develop relatively straightforward methods for estimating the imperfection sensitivity in the collapse load of structures carrying compressive loads. Particularly for shell structures, it is generally understood that the interaction between multiple buckling modes affects the postcritical behaviour of the structure, and that this implies that small imperfections in the initial shape of the shell will have a disproportionate impact on the failure load of the structure. Nonlinear computational methods can be excellent at capturing the development of initial imperfections, and reproducing the behaviour observed during experiments. However, these calculations are expensive, and hence, for instance, difficult to use in a design context. This presentation will show developments based on understanding how the stiffness of a structure varies with variations in load, and variations in geometry. The aim is to give computational methods that can quickly estimate the load carrying capacity of an imperfection sensitive structure.

Keywords: imperfection sensitivity, stiffness, design

Nonlinear Struts Under Parametric Excitation: Resonance Characterization

Yu Cheng[a], M. Ahmer Wadee[a] & Christian Malaga-Chuquitaype[a]

[a] Department of Civil and Environmental Engineering, Imperial College London, London, United Kingdom

E-mail: yu.cheng21@imperial.ac.uk

Abstract

Since nonlinear struts under parametric excitation can suddenly switch from high to low axial stiffness, they can be potentially used in energy harvesting and vibration suppression systems. The present study investigates the nonlinear dynamic behaviour of simply-supported parametrically excited buckled struts under time-dependent axial loading. The extended Hamilton's principle is implemented to derive the governing differential equations of motion for lateral vibrations and Galerkin's method is subsequently used to simplify the analysis by focusing the discussion to the first vibration mode.Numerical continuation techniques are used to explore the behaviour described by the nonlinear differential equations of motion. Frequency response functions are presented; bifurcations, including limit points of cycles, period-doubling bifurcations and their respective loci are analysed through two- and three-parameter numerical continuation. A detailed study reveals that these distinct responses are demarcated into different parameter spaces by the loci of the aforementioned bifurcations. The results are verified numerically against solutions obtained from a finite element model developed within the commercial code ABAQUS with good agreement being found. The findings demonstrate that the proposed model offers a fast and accurate approach for analysing the nonlinear dynamics of parametrically excited buckled struts, providing valuable insights for structural isolation and energy harvesting systems.

Keywords: Nonlinear dynamics, struts, resonance, bifurcations

Testing and modelling of collapse mechanisms in cellular aluminium foams

Finian McCann [a], **Gabrielle Marshall** [a] **& Gbolahan Salako** [a]

[a] School of Architecture, Building and Civil Engineering, Loughborough University, UK

E-mail: F.McCann@Lboro.ac.uk

Abstract

Metallic foams can offer enhanced energy absorption performance under significant impact or blast loads, with applications in the civil, structural, maritime and defence industries. Such behaviour, observed at the macroscale, manifests via highly ductile plastic buckling of the walls of individual cells occurring in succession at the micro- to mesoscale. In this study, a series of structural panel specimens consisting of aluminium foam sandwiched between steel plates are loaded in compression under different displacement rates; of particular note, with the relative density of the foams varying noticeably across the specimen set. During compression testing, high-resolution Digital Image Correlation (DIC) optical strain metrology is applied to capture local concentrations of strain that signify the onset of local cell wall buckling, with the evolution of densification observable upon inspection of the deformed state throughout its load-deflection history; results for 0.3% proof stress, plateau stress and stress at 50% strain are also discussed. The influence of relative foam density on these properties and moreover on the propagation of cell wall buckling through the foam matrix is described. Finally, indicative numerical analyses employing standard Deshpande-Fleck [1] material models are confirmed to achieve good agreement with the experimental results up to intermediate level of strains, but significant deviations are observed at higher strains owing to changes in the plastic Poisson's ratio of the material that are not captured by these models, which are typically employed in commercial finite element modelling software. A simplified stress-strain curve correction method is demonstrated, which improves accuracy across the ranges of strain observed during experiments while remaining compatible with standard material models.

Keywords: metallic foams, energy absorption, cell wall instability

References:

[1] V.S. Deshpande, N.A. Fleck. 2000. Isotropic constitutive models formetallic foams, *Journal of the Mechanics and Physics of Solids*, 48(6–7):1253–1283.

Analytical investigation of the buckling behavior of sandwich structures with anisotropic/thin-walled cores

Robin Turlin [a] **&** **Philippe Le Grognec** [a]

[a] ENSTA, Institut Polytechnique de Paris, UMR CNRS 6027, IRDL, F-29200 Brest, France

E-mail: philippe.le_grognec@ensta.fr

Abstract

The buckling analysis of a sandwich structure is much more complicated than that of a monolithic one displaying only global buckling modes. Owing to the presence of thin/slender parts (among which the two faces), a sandwich structure is prone to buckling under any loading configuration leading to global or local compression effects. When considering a sandwich beam-column under overall axial compression, local buckling responses are very likely to occur. These face wrinkling phenomena, in the same way as the global buckling solution, highly depend on the nature of the core layer. Up to now, many analytical solutions have been developed in the literature for the classical case of an homogeneous and isotropic core material [1]. The present study deals with the more general case of anisotropic cores, including possibly the case of laminated composite faces [2]. The modeling approach is based on the use of a laminated beam model for the faces whereas the core layer is represented as a 2D continuous solid. With such a formulation, analytical solutions can be obtained for the critical loadings and the associated buckling modes, by means of a bifurcation analysis. The strong influence of the orthotropy ratio of the core material on the occurrence of symmetric or antisymmetric wrinkling modes is emphasized. This approach also allows one to deal with heterogeneous core structures (like honeycombs) in an homogenized way. In this context, the use of a micropolar continuum to describe the core behavior is also investigated [3]. All the analytical solutions are confronted to numerical results derived from 2D linearized buckling finite element computations, for validation purposes.

Keywords: Buckling/wrinkling, Sandwich structures, Anisotropic core, Analytical solutions.

References:

[1] A.S. Benson, J. Mayers, General instability and face wrinkling of sandwich plates: Unified theory and applications, AIAA J. 5 (1967) 729–739.

[2] M. D'Ottavio, O. Polit, Linearized global and local buckling analysis of sandwich struts with a refined quasi-3D model, Acta Mech. 226 (2015) 81–101.

[3] V.K. Mehta, A.R. Srinivasa, J.N. Reddy, Energy equivalence-based homogenized micropolar model for 2D high valency architected materials: Periodic, semi-periodic, and aperiodic, Mechanics Research Communications 149 (2025) 104530.

An Analytical Approach to the Stability Design of Struts with Nonlinear Materials

M. Ahmer Wadee[a], **Anton Köllner**[a] **& Leroy Gardner**[a]

[a] Department of Civil and Environmental Engineering, Imperial College London, London, UK

E-mail: a.wadee@imperial.ac.uk

Abstract

There has been considerable activity in the structural engineering field over the last three decades investigating the behaviour and design of metallic structural members that have rounded constitutive behaviour. In particular, members made from stainless steel and aluminium alloys have received considerable attention [1]. It has been determined in many studies that approximating the behaviour as a "linearly elastic–perfectly plastic" material results in design predictions that are overly conservative and hence would produce inefficient designs. However, conventional analytical modelling techniques that use the tangent modulus approach to obtain the buckling strength for such members require iteration to obtain a solution, while some codes of practice still rely on more empirical methodologies to provide buckling strength predictions. The present work addresses this problem through an energy formulation, based on techniques developed by Thompson and Hunt [2], for columns made from materials that can be described by the Ramberg–Osgood constitutive law. This law is often used in some form for modelling cold-formed steelwork, stainless steel, and aluminium alloys. The developed equations and formulae are compared with existing experimental data for structural hollow cross-sections with good agreement. Subsequently, new design provisions are developed that meet the reliability requirements within the structural Eurocodes [3].

Keywords: Ramberg–Osgood materials, Energy methods, Flexural buckling, Design procedures

References:

[1] L. Gardner, Stability and Design of Stainless Steel Structures – Review and Outlook, Thin-Walled Struct. 141 (2019) 208–16.

[2] J.M.T. Thompson, G.W. Hunt, A General Theory of Elastic Stability, Wiley, New York, 1973.

[3] A. Köllner, L. Gardner, M.A. Wadee, A New Approach to the Stability Design of Ramberg–Osgood material struts, Structures, 56 (2023) 104844.

Structural stability analyses with path-following techniques for semi-analytical modelling

Anton Köllner [a]

[a] Department of Civil and Environmental Engineering, Imperial College London, London, United Kingdom

E-mail: a.koellner@imperial.ac.uk

Abstract

Structural instability phenomena can be efficiently explored with semi-analytical models. Studying perfect (as well as imperfect) systems alongside facilitating comprehensive parametric studies provides fundamental understanding of the stability behaviour of structures. However, conventional solution algorithms often fall short in harnessing the full potential of semi- analytical models by implementing a load or displacement-controlled scheme as well as focusing on single isolated failure modes. As a consequence, some insights into the stability behaviour may be missed, particularly whenever complex instabilities, such as mode interactions and compound bifurcations , occur. Complex instability phenomena can be explored via numerical continuation techniques often referred to as path-following. The current work presents a path- following algorithm developed for semi-analytical modelling approaches in which geometric instabilities such as buckling as well as material instabilities associated with material damage can be investigated [1]. The path-following algorithm is formulated in the context of a discrete coordinate approach with generalized coordinates, control/load and damage parameters describing the structural configuration, the loading and damage state of the mechanical systems, respectively. The path-following algorithm facilitates efficient analyses of (quasi-static) instability phenomena such as distinct and compound bifurcations, secondary bifurcations (triggering mode interactions), and interactions of buckling instabilities with material damage. Moreover, loci of critical points for geometric and material instabilities can be traced and analysed. The application of the path-following algorithm to semi-analytical models provides complete stability landscapes for structures which results in improved understanding of the stability behaviour.

Keywords: Structural stability, Path-following, Energy methods, Semi-analytical modelling

References:

[1] A. Köllner, N. Lüer, A path-following approach for quasi-static structural and material instability phenomena, Computer Methods in Applied Mechanics and Engineering, 436 (2025) 117704.

Sandwich Beams Destabilizing Effect of the Load

Avi Wurf [a], **Yeoshua Frostig** [a] **& Oded Rabinovitch** [a]

[a] Faculty of Civil and Environmental Engineering, Technion-Israel Institute of Technology, Haifa, Israel

E-mail: *aviwurf@campus.technion.ac.il*

Abstract

Lateral-torsional instability characterizes beams subjected to bending about the major axis, which can suddenly shift to a new state of biaxial bending and twist. This phenomenon has been extensively investigated in the context of I-shaped steel beams. However, in sandwich beams, it has received attention only recently, and only to a rather limited range of conditions. The destabilizing effect of the load, a key factor in this unique phenomenon, was not addressed at all in the context of sandwich beams. The interaction between the destabilizing effects and other sandwich-specific phenomena, such as potential interfacial degradation, face-sheet wrinkling, cross-sectional distortions, and localized effects, was also not addressed. All of these are open questions that still need to be answered. This study explores the destabilizing effect of the load on the lateral-torsional instability of soft-core sandwich beams. Due to the layered configuration, characterized by significant differences in thickness and mechanical properties, and the cross-sectional distortions induced by the deformability of the core, amplification of this effect and, correspondingly, sensitivity to the location of the load are expected. Direct concentrated loading of the face sheets in soft-core sandwich beams can cause localized effects, such as indentation, cross-sectional distortion, and stress concentration. Adding this aspect to the global lateral-torsional instability is expected to induce strong interactions with other instabilities typical of such structures, such as wrinkling, further impacting the nonlinear response and amplifying the destabilizing effect. The quantification of this range of phenomena is the focus of the current investigation. The study employs an analytical methodology that combines geometrically nonlinear analysis with a high-order torsional sandwich beam theory. The latter integrates the rich stress and deformation fields in the compliant core into the analysis. Quantitative results focus on the impact of the load's location on the critical instability point, the overall nonlinear response, its interaction with other instabilities, and its impact on the localized effects. The presentation highlights these aspects and assesses their impact on the performance of soft-core sandwich beams.

Keywords: Lateral-torsional instability, soft-core sandwich beams, destabilizing effect of the load, Instabilities interaction

MS11

Dynamic Behavior of Hysteretic Mechanical Systems Subjected to External Pulse Forces

Nicolò Vaiana, **Raffaele Capuano**

Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy

E-mail: nicolo.vaiana@unina.it

Abstract

This study examines the response of a broad class of single degree of freedom nonlinear dynamic systems, exhibiting rate-independent hysteretic behavior, under the action of external pulse forces. To this end, the nonlinear equilibrium equation, the expressions to compute the rate-independent hysteretic and external pulse forces, and the relation describing the modified work-energy theorem are first provided in both dimensional and nondimensional forms. Then, to introduce the framework for the ensuing investigation, a typical hysteretic mechanical system, subjected to external pulse forces, is preliminarily analyzed in terms of nondimensional dynamic and maximum responses. Subsequently, several sets of nondimensional displacement, velocity, and acceleration shock spectra are presented to study the effects produced by the properties related to the rate-independent hysteretic force and the external pulse forces on the complex responses of the examined hysteretic mechanical systems. In conclusion, a final mechanical system, supported by four wire rope isolators and loaded by external pulse forces, is analyzed to evaluate the influence of the asymmetric force-displacement hysteresis loops, characterizing the experimental behavior of the adopted rate-independent hysteretic devices, on its dynamic response.

Keywords: mechanical hysteresis, pulse force, shock spectrum

A 3d Printed Meta-Basement for Vibration Control: Preliminary Analytical, Numerical, and Experimental Results

Salvatore Vecchiè [c], **Raffaele Capuano** [a], **Fabrizia Cilento** [b], **Daniele Losanno** [a], **Nicolò Vaiana** [a]

[a] Department of Structures for Engineering and Architecture, University of Naples Federico II, Italy
[b] Institute for Polymers, Composites and Biomaterials, Consiglio Nazionale delle Ricerche, Italy
[c] Scuola IMT Alti Studi Lucca, Italy

E-mail: nicolo.vaiana@unina.it

Abstract
This study is focused on the development of a new engineered basement for the vibration protection of mean scale rigid bodies represented by works of art or sensitive equipment placed in strategic private and public buildings. The proposed engineered basement, referred to as *meta-basement*, is made up of a series of rigid unit cells that may be organized into one or more horizontal layers. Each unit cell contains a single resonator which is connected to the horizontal or vertical cell walls by means of a linear elastic element. Being the latter deformable, the resonator is able to move along the vertical or horizontal direction. In the present study, we preliminary propose an analytical expression to compute the band gap associated with the single unit cell. Then, the latter is modelled via a Finite Element approach and the fundamental natural frequency values provided by both the analytical and numerical methods are compared with the one obtained from some experimental tests carried out on a 3d printed unit cell. Finally, to assess the effectiveness of the proposed device in controlling vibrations, a series of numerical simulations are performed by means of the computer program Abaqus on a meta-basement composed of two horizontal layers, each one made up of six unit cells.

Keywords: meta-basement, resonator, vibration control

On the Influence of the Hysteresis Loop Shape on the Dynamics of Rocking Systems

Raffaele Capuano [a], **Nicolò Vaiana** [a] **& Luciano Rosati** [a]

[a] Department of Structures for Engineering and Architecture, University of Naples Federico II, Via Claudio, 21, 80124, Napoli, Italy.

E-mail: raffaele.capuano@unina.it

Abstract

We investigate the dynamic behavior of rate-independent hysteretic rocking systems subjected to harmonic excitation. Such systems are increasingly adopted for vibration mitigation in civil and mechanical applications, where controlled rocking and energy dissipation play a key role. Particular attention is devoted to the influence of different hysteresis loop shapes on the frequency response curves, as well as on the stability and bifurcation characteristics of the system. Starting from the equations of motion of a rocking mass equipped with hysteretic elements, a non-dimensionalization procedure is applied to reduce the number of governing parameters and to identify the fundamental quantities controlling the system dynamics. The hysteretic behavior is modeled using the Vaiana-Rosati Model (VRM), which provides a unified phenomenological representation of a wide class of rate-independent hysteresis loops [1]. Periodic responses under harmonic forcing are computed by means of a continuation method based on Poincaré maps and pseudo arclength path-following [2]. This approach enables the efficient tracking of frequency response curves, as well as the detection of stability changes and bifurcation phenomena. Numerical results show that the hysteresis loop shape significantly affects the system response, leading to softening or hardening behavior, variation in resonance amplitudes, and different stability scenarios. The influence of combining hysteretic elements with different loop shapes is also studied, revealing additional dynamic features [3]. The research provides useful insight into the design and optimization of hysteretic rocking systems subjected to dynamic loads and support the development of resilient and energy- efficient vibration control solutions.

Keywords: hysteretic rocking systems, frequency response, stability, bifurcation

References:

[1] N. Vaiana, L. Rosati, Classification and Unified Phenomenological Modeling of Complex Uniaxial Rate-Independent Hysteretic Responses, Mechanical Systems and Signal Processing 182 (2023) 109539.

[2] W. Lacarbonara, F. Vestroni, Nonclassical responses of oscillators with hysteresis. Nonlinear Dynamics (2003), 32(3), 235-258.

[3] R. Capuano, B. Carboni, N. Vaiana, Rate-Independent Hysteretic Rocking Systems: Frequency Response, Stability and Bifurcation, *Nonlinear Dynamics* 113 (2025) 30671–30688.

Achieving mechanical nonreciprocity through gap-based design

Xiang Chen [a], **Vahid Shobeiri** [a] **& Yi Min Xie** [b,a,*]

[a] Centre for Innovative Structures and Materials, School of Engineering, RMIT University, Melbourne 3001, Australia

[b] College of Future Technologies, Hohai University, Changzhou, Jiangsu 213200,

China

E-mail: mike.xie@rmit.edu.au

Abstract

Nonreciprocity has gained significant attention across various fields due to its potential to enable the direction-dependent transmission of signals or energy. To date, researchers have made notable progress in exploring nonreciprocal phenomena by breaking spatial or temporal symmetry. However, existing approaches generally rely on complex material compositions or precisely engineered structural geometries, posing a typical challenge in developing a robust implementable method for achieving static mechanical nonreciprocity. This work proposes a simple yet general passive method that introduces through-thickness gaps to break reciprocity. The unit cell featuring gaps under opposite loadings is first examined, and then its extension to an array of unit cells is investigated. Numerical and experimental results demonstrate that implementing through-thickness gaps can effectively break the deformation symmetry, thereby enabling static mechanical nonreciprocity. The results further reveal that mechanical nonreciprocity is fundamentally governed by the kinematic alignment between the prescribed gap configuration and the localized strain fields, with centrally and symmetrically distributed gaps effectively exploiting dominant shear deformation zones to trigger pronounced contact nonlinearity. The findings from this work open an effective avenue for realizing mechanical nonreciprocity and provide a basis for the design of nonreciprocal systems.

Keywords: mechanical nonreciprocity, through-thickness gaps, asymmetric responses, passive method.

Experimental validation of Fiber Reinforced Elastimeric Isolators for seismic isolation of bridges with non-linear viscous dampers

Daniele Losanno[a], **Pio Medaglia**[a], **Shiv Prakash**[b], **Giorgio Serino**[a]

[a] Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy

[b] Department of Earthquake Engineering, Indian Institute of Technology Roorkee, Roorkee, India,

E-mail: daniele.losanno@unina.it

Abstract

This study presents a bridge model (length scale 1:1.5) designed with an innovative control system combining fiber reinforced elastomeric isolators (FREIs) and non-linear viscous dampers (VD). Seismic isolation of bridges aims at reducing the force demand on piers by elongating the structural period. This benefit is typically accompanied by large isolator displacements, therefore a certain level of supplemental damping could be beneficial in limiting deck displacements while preserving the benefits of isolation. In present study FREIs were designed for a target displacement of 100 mm to ensure a vibration period of the bridge model of around 2.0 seconds. In order to limit the deck-to-pier displacement VDs were added after proper calibration of the constitutive parameters. In case of existing bridges, FREIs offer the main advantage of preventing mechanical connections of the devices while VDs can limit the displacement thus preventing instability of the isolation system and reducing seismic gaps. Numerical analysis of the bridge model with FREIs confirmed a significant reduction of the base shear compared to a fixed base configuration. When VDs are added to FREIs, the displacament demand at the deck level reduces up to 50% while slightly increasing the base shear. Under preliminary characterization tests FREIs and VDs were tested up to 140 mm lateral displacement and 0.4 m/s peak velocity, respectively. Theoretical results will be validated through a shaking table experimental program to demonstrate the effectiveness of FREIs in providing resilient and sustainable solutions for existing infrastructures.

Keywords: bridge isolation, FREIs, dampers, shake table.

Seismic Vulnerability Control of Steel Moment-Resisting Frames Using Optimum Multiple Friction Tuned Mass Dampers

Mohsen Khatibinia[a], Hessam Yazdani[b], Fatemehsadat Moosavinezhad[a] & Sadjad Gharehbaghi[c]

[a] Department of Civil Engineering, University of Birjand, Birjand, Iran
[b] Department of Civil and Environmental Engineering, University of Missouri, Columbia, MO, USA
[c] Department of Civil Engineering, Sharif University of Technology, Tehran, Iran

E-mail: hyazdai@missouri.edu

Abstract

The friction-tuned mass damper (FTMD) is a passive control device that consists of a TMD enhanced with dry friction damping and a rate-independent hysteretic restoring mechanism. Since FTMD is highly sensitive to errors in the natural frequency of the target structure, incorrect parameter selection may amplify structural vibrations rather than mitigate them. To overcome this limitation, this study proposes the design and optimum layout of a multiple FTMD (MFTMD) system that mitigates the seismic vulnerability of steel moment-resisting frames (MRFs) by distributing damping effects across a range of frequencies. The objective function is the average maximum story damage under a set of scaled real ground motions. Nonlinear dynamic analyses are carried out to represent the frictional hysteresis of the FTMDs and the inelastic response of the steel MRF. Seismic damage is represented by a linear combination of deformation and hysteretic energy dissipation in structural elements. Constraints are formulated to achieve a more uniform story damage distribution while limiting the maximum stroke length of the FTMDs. A hybridization of binary and real particle swarm optimization algorithms is used as the optimizer. The proposed approach is demonstrated using a 10-story inelastic steel MRF equipped with either an optimized single FTMD located at the roof or an optimized MFTMD system. The results indicate that the steel MRF equipped with the optimized MFTMD sustains the least damage and exhibits the most uniform damage distribution among the assessed cases. Furthermore, seismic fragility assessments reveal that the optimal MFTMD system significantly reduces the vulnerability of the steel MRF across various damage states and provides a practical optimization-based design procedure for nonlinear passive protection devices.

Keywords: Friction-tuned mass damper, Passive control, Nonlinear hysteresis modeling, Optimization-based seismic design

References:

[1] M. Khatibinia, S. Gharehbaghi, H. Yazdani, S. Akbari, Optimum Design and Layout of Multiple Tuned Mass Dampers for Seismic Damage Control of Steel Frame Buildings, J. Build. Eng. 100 (2025) 111759.

[2] M. Khatibinia, S. Akbari, H. Yazdani, S. Gharehbaghi, Damage-Based Optimal Control of Steel Moment-Resisting Frames Equipped with Tuned Mass Dampers, J. Vib. Control 30 (2024) 659–672.

Safe Reinforcement Learning for Active Train Vibration Control under Train-Bridge Interaction

Li Zhu [a] & Yufeng Gu [a]

[a] School of Civil Engineering, Beijing Jiaotong University, Beijing, China

E-mail: zhuli@bjtu.edu.cn

Abstract

The Root Mean Square (RMS) of car body vertical acceleration is a primary indicator of ride comfort for railway operations, while the wheel unloading ratio is a critical safety indicator associated with reduced wheel–rail contact. Under train–bridge interaction (TBI), bridge flexibility and coupled dynamics introduce additional vibration modes and deteriorate both comfort and safety margins. The performance of conventional control approaches is often limited in TBI environments due to model uncertainty, unmeasured disturbances, and strong train–bridge coupling, making it difficult to improve comfort without sacrificing safety margins. To address these challenges, this presentation proposes a safe deep reinforcement learning (RL) framework for active vertical vibration control of trains under TBI. A steel–concrete composite bridge model and a multi-degree-of-freedom train model are integrated into an RL environment, and the coupled model has been validated against measured bridge response data to ensure physical fidelity. Actuators of the train suspensions are explicitly represented using a first-order dynamics model with saturation, rate limits, and delay. Safety is enforced by casting the control task as a constrained Markov decision process (CMDP) with the wheel unloading ratio as an explicit constraint. Specifically, we adopt a Lagrangian actor–critic scheme, where the critic estimates expected cumulative return and the Lagrange multiplier is updated online to adaptively balance comfort improvement and safety preservation. Simulation results will be benchmarked against model predictive control (MPC) and unconstrained RL, demonstrating favorable comfort–safety performance of the proposed safe RL.

Keywords: train–bridge interaction, safe reinforcement learning, wheel unloading ratio, active vibration control

References:

[1] Q. Zhu, S.-M. Wang, Z.-B. Zhou, and Y.-Q. Ni, Enhanced Deep Reinforcement Learning Controller for Maglev Train-guideway Coupling Systems in Crosswind Conditions, Vehicle System Dynamics, pp. 1–23, Aug. 2025, doi: 10.1080/00423114.2025.2539268.

[2] S. Bhatnagar, An Actor–critic Algorithm with Function Approximation for Discounted Cost Constrained Markov Decision Processes, Systems & Control Letters, vol. 59, no. 12, pp. 760–766, Dec. 2010, doi: 10.1016/j.sysconle.2010.08.013.

Seismic Control Performance of Structures Equipped with Active Variable Inerter-Based Tuned Mass Dampers

Chang-Ching Chang [a] & Jer-Fu Wang [b]

[a] National Center for Research on Earthquake Engineering, NIAR, Taipei, Taiwan
[b] Department of Civil and Disaster Prevention Engineering, Nation United University, Miao Li, Taiwan

E-mail: ccchang@niar.org.tw

Abstract

Tuned Mass Damper (TMD) systems have been widely implemented in engineering structures and mechanical systems to suppress dynamic responses induced by external excitations. However, the control performance of a conventional passive TMD can significantly deteriorate when its natural frequency deviates from the target tuning condition. To address this limitation, recent studies have proposed the use of flywheel-based inerter mechanisms with variable mass moments of inertia to adaptively adjust the effective frequency of the TMD and mitigate the detuning effect. In this study, an Active Variable Inerter-Based Tuned Mass Damper (AVI-TMD) is developed to achieve real-time control of inertance through a feedback-driven DC motor integrated with a transmission system. Theoretical formulations are established to describe the dynamic interaction between the motor torque, transmission mechanism, and equivalent inertance of the AVI-TMD using H-infinity active control theory. This framework provides a robust control basis for regulating the variable inertance and maintaining system stability under seismic excitations. Numerical simulations are conducted on multiple-degree-of-freedom structural models subjected to earthquake ground motions to evaluate the seismic control performance and to identify optimal system parameters. The results demonstrate that the proposed AVI-TMD system effectively enhances vibration suppression, maintains robustness against frequency detuning, and broadens the control bandwidth. The findings highlight the potential of active variable-inerter-based damping devices for advanced seismic vibration control applications in structural and mechanical engineering.

Keywords: Tuned Mass Damper, Variable Inerter, Active Control, Seismic Performance

References:

[1] Lin, G.L., Chang, C.C., Lin, C.S., Lin, C.C., Lin, T.T., Li, Y.H. Experimental investigation of an electromagnetic seismic isolation system with different configurations of inertanc. Journal of Sound and Vibration, 595, (2025).

[2]. Chang, C.C. Wang, J.F., Lin, C.C. Control Parameters Design of Tuned Mass Dampers with Active Variable Inerter. The 8th Asia Conference on Earthquake Engineering (8ACEE), Taipei, Taiwan, November 9-11, (2022).

[3]. Chang, C.C., Wang, J.F., Lin, C.C. Lin, T.T., Lin, C.S. Optimal Design of Tuned Mass Dampers with Variable Inerter and Damping. ASME 2019 Pressure Vessels & Piping Conference (PVP 2019), San Antonio, TX, USA, July 14-19. (2019).

MS12

Electromechanical Response of Self-Sensing Cement-Based Composites under Cyclic Loading and AC Excitation

Paolino Cassese [a], Luigi Cieri [a], Carlo Luca Schiavi [b], Antonio Bonati [b] & Carlo Rainieri [a]

[a] Construction Technologies Institute (ITC), National Research Council of Italy (CNR), Naples, Italy
[b] Construction Technologies Institute (ITC), National Research Council of Italy (CNR), San Giuliano Milanese, Italy

E-mail: cassese@itc.cnr.it

Abstract

Reinforced concrete (RC) structures are widespread across the Mediterranean region of Europe, particularly in Italy, and are often affected by aging-related degradation and exposure to natural and anthropogenic hazards. Continuous Structural Health Monitoring (SHM) represents a promising strategy to extend their service life and enhance structural reliability. Among emerging sensing technologies, self-sensing cement-based composites (SSCCs) have attracted increasing interest due to their intrinsic compatibility with RC members and their ability to provide distributed strain-sensing capabilities. SSCCs are typically manufactured by incorporating conductive nanofillers into conventional cementitious matrices to induce piezoresistive behavior. However, their metrological performance strongly depends on several factors, including filler type, dispersion technique, and measurement configuration, particularly the nature of the electrical excitation (direct current, DC, versus alternating current, AC). Although DC excitation is widely adopted, several limitations have been highlighted in the literature, motivating further investigation into AC-based approaches.

This study experimentally investigates the electromechanical response of SSCC specimens (40 × 40 × 160 mm^3) produced by incorporating COOH-functionalized multi-walled carbon nanotubes into a cement paste matrix. Quasi-static cyclic compression tests were performed by applying axial loading along the longitudinal direction of the specimens. During testing, an AC electrical input was imposed, while mechanical strain and electrical response were continuously monitored to evaluate the main sensing and calibration parameters. The results demonstrate promising strain-sensing performance and highlight a significant influence of the AC signal characteristics on the piezoresistive response of the material.

Keywords: self-sensing cement-based composites, structural health monitoring, electromechanical response, functionalized multi-walled carbon nanotubes, AC excitation.

Smart Piezoelectric Bearings for Bridge-Based Vehicle Identification

Alessandro Guarnieri [a], Caterina Levati [a] & Francesco Petrini [a]

[a] Sapienza University of Rome, Department of Structural Engineering, Rome, Italy

E-mail: Francesco.petrini@uniroma1.it

Abstract

Modern traffic spectra are evolving rapidly due to changes in vehicle fleets, logistics patterns, and loading practices. As a consequence, code-prescribed traffic models are not always representative of the actual demand experienced by bridges. Access to site-specific, continuously updated traffic spectra can therefore provide a more realistic basis for structural assessment and enables network-level decision making by supporting the definition of bridge-by-bridge maintenance priorities based on measured usage rather than assumed loading scenarios. In this context, piezoelectric bearings (PiBs) are proposed as multifunctional bridge components that couple an elastomeric support with an embedded flexible piezoelectric plate. Under moving vehicle loads, vertical bearing deformation excites an internal oscillating (bender-like) element, generating voltage and electrical power [1]. While PiBs are conceived primarily for piezoelectric energy harvesting (supporting small, self-powered sensing and communication nodes) their electrical outputs also act as information-rich signatures of vehicle passages, enabling traffic monitoring without dedicated pavement instrumentation [2]. This work investigates the use of PiB-generated electrical signals for moving vehicle identification through a multi-parameter classification approach. The method analyzes the voltage/power response within automatically detected event windows, extracts features associated with axle-induced excitation and identifies sequences of electrical power peaks that are mapped to vehicle categories. The same framework supports the estimation of key kinematic descriptors, including vehicle speed and axle count, by exploiting timing relationships between peaks and consistency checks within the event window [3]. The study is developed through numerical methods, combining traffic simulations and finite-element modelling at multiple scales. A global bridge model is used to reproduce realistic load distribution under moving vehicles, a mechanical bearing model transfers support demand to local kinematics, and a coupled electromechanical model predicts the PiB electrical response under resistive loads. The results demonstrate the potential of PiBs to jointly harvest energy and sense traffic, providing a scalable route toward autonomous monitoring networks and data-driven traffic spectrum characterization.

Keywords: Piezoelectric Bearings, Moving Load Identification, Energy Harvesting

References:

[1] Peigney, M., & Siegert, D. Piezoelectric energy harvesting from traffic-induced bridge vibrations. Smart Materials and Structures, 22(9), 095019 (2013). DOI: 10.1088/0964-1726/22/9/095019.

[2] Chen, S.-Z., Wu, G., & Feng, D.-C. Development of a bridge weigh-in-motion method considering the presence of multiple vehicles. Engineering Structures, 191, 724–739 (2019). DOI: 10.1016/j.engstruct.2019.04.095.

[3] Wang, H., Nagayama, T., Kawakatsu, T., & Takasu, A. A Data-Driven Approach for Bridge Weigh-in-Motion from Impact Acceleration Responses at Bridge Joints. Structural Control and Health Monitoring, Volume 2023, Article ID 2287978 (2023). DOI: 10.1155/2023/2287978.

Piezoelectric Bearings (PiBs) for Sustainable Structural Health Monitoring of bridges

Alessandro Guarnieri [a] **& Francesco Petrini** [a]

[a] Sapienza University of Rome, Department of Structural Engineering, Rome, Italy

E-mail: Alessandro.guarnieri@uniroma1.it

Abstract

The increasing demand for sustainability in bridge engineering, emphasizing the reduction of energy consumption in Structural Health Monitoring (SHM) systems and the extension of bridge service life as two crucial and still developing goals, has inspired the conception of Piezoelectric Bearings (PiBs) for smart and sustainable bridges. These innovative devices are integrated into bridge bearings with a dual purpose: energy harvesting and moving load identification. PiBs are composite elements arranged in parallel, where piezoelectric plates are embedded within elastomeric isolators. When excited by vibrations induced by vehicular traffic, they convert the kinetic energy of the oscillating bridge into electrical energy [1]. In this way, piezoelectric energy harvesting (PEH) technologies, already established in other engineering sectors, are successfully transferred to bridge applications [2]. With the rapid evolution of the microsensor industry, capable of producing increasingly efficient and miniaturized sensors such as MEMS, the power demand of SHM systems has been drastically reduced. Following this trend of minimizing the energy required by monitoring sensors, PiBs offer a sustainable and self-sufficient solution: through small accumulators, the energy generated by traffic induced vibrations can supply essential sensors, eliminating the need for disposable batteries or complex wiring. Moreover, considering the growing importance of Average Annual Daily Traffic (AADT) estimation for evaluating fatigue-related phenomena and predicting the remaining service life of steel or composite bridges, this study investigates the correlation between the energy produced by a passing vehicle and its weight [3]. Once this correlation law is established, the PiB system will enable indirect AADT estimation from measured energy values over a given period, providing a valuable and energy-efficient tool for SHM and predictive maintenance of bridge infrastructures.

Keywords: Piezoelectric Bearings, Energy Harvesting, Moving Load Identification

References:

[1] Peigney, M., & Siegert, D. Piezoelectric energy harvesting from traffic-induced bridge vibrations. Smart Materials and Structures, 22(9), 095019 (2013). DOI: 10.1088/0964-1726/22/9/095019.

[2] F. U. Khan and I. Ahmad, "Review of Energy Harvesters Utilizing Bridge Vibrations," Shock and Vibration, 2015.

[3] Z. Zhang, H. Xiang, Z. Shi and J. Zhan, "Experimental investigation on piezoelectric energy harvesting from vehicle-bridge coupling vibration," Energy Conversion and Management, vol. 163, pp. 169-179, 2018

Sensor-Enabled Geosynthetics for Stabilization and Instrumentation of Earth Systems: Development, Testing, and Multiscale Simulations

Hessam Yazdani[a] **& Kianoosh Hatami**[b]

[a] Department of Civil and Environmental Engineering, University of Missouri, Columbia, MO, USA
[b] School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, OK, USA

E-mail: *hyazdai@missouri.edu*

Abstract

Performance monitoring is increasingly integrated into geotechnical and transportation projects to quantify deformations, detect serviceability trends, and reduce uncertainty in design and construction. Sensor-enabled geosynthetics (SEG) are polymer nanocomposites that provide reinforcement and stabilization while enabling distributed strain sensing through an intrinsic electromechanical response. In SEG, strain sensing is achieved through tensoresistivity, defined as the sensitivity of electrical conductivity to tensile strain. This work presents the current state of development of SEG technology and summarizes experimental and multiscale simulation advances supporting its design, calibration, and deployment. In-isolation tensile tests are used to characterize mechanical response and the strain–resistivity relation, including repeatability and sensitivity over relevant strain ranges. Complementary tests with SEG embedded in soil are reported to quantify changes in electromechanical response associated with confinement, interface effects, and soil–reinforcement interaction. Advanced multiscale simulations spanning atomistic to large-scale finite element simulations linking microstructural conduction mechanisms and damage evolution to macroscopic tensoresistive response are introduced, and differences between in-isolation and in-soil behavior are interpreted. The combined experimental–computational dataset defines the present performance bounds of SEG and identifies conditions under which the sensing function is stable and interpretable for structural health monitoring. Research directions required for field implementation, including calibration protocols for soil-specific conditions, durability, scalable manufacturing routes, and data acquisition strategies for large geotechnical systems, are also highlighted.

Keywords: Sensor-enabled geosynthetics; Tensoresistivity; Structural health monitoring; Soil–reinforcement interaction

References:

[1] H. Yazdani, B.E. Smith, K. Hatami, Electrical Conductivity and Mechanical Performance of Multiwalled CNT-Filled Polyvinyl Chloride Composites Subjected to Tensile Load, J. Appl. Polym. Sci. 133 (2016).

[2] H. Ghasemi, H. Yazdani, Atomistic Simulation and Machine Learning Predictions of Mechanical Response in Nanotube-Polymer Composites Considering Filler Morphology and Aggregation, Comput. Mater. Sci. 246 (2025) 113399.

Towards Self-Sensing Masonry: Development of Hybrid Carbon-Doped Conductive Mortars

Ryan Araujo de Matos [a], Antonella D'Alessandro [a], Israel Nilton Lopes Sousa [a], Filippo Ubertini [a]

[a] . Department of Civil and Environmental Engineering, University of Perugia, Via G. Duranti, 93 06125 Perugia (PG) Italy

E-mail: antonella.dalessandro@unipg.it

Abstract

This research work focuses on the development of smart cementitious mortars for damage detection in masonry structural elements. The main objective is to create an intelligent masonry system capable of sensing deformation changes and monitoring the initiation and propagation of cracks through the integration of smart bricks. The proposed approach is based on the design of a functional mortar with enhanced sensing capabilities. The developed mortar has been specifically optimized for real-scale masonry applications, taking into account both physical and technological requirements necessary for practical implementation. In particular, the mixture design ensures adequate workability, compatibility with traditional construction techniques, and suitability for large-scale applications. To achieve self-sensing properties, conductive fillers were incorporated into the cementitious matrix. The selected fillers include carbon microfibers and graphite, which differ in aspect ratio but can both be effectively dispersed using standard mixing procedures commonly adopted in masonry construction. This choice allows for scalability and ease of application without requiring specialized equipment or processes. The constituent materials were carefully selected to ensure that the resulting mortar remains suitable for real construction practices while exhibiting enhanced functional properties. Within this study, several key parameters were investigated, including density, workability, electrical conductivity, and sensitivity to mechanical loading and damage evolution. Experimental results demonstrate that the appropriate combination of conductive inclusions and matrix composition leads to cementitious mortars with reliable self-sensing capabilities. In particular, the material shows a clear response to strain variations and crack propagation, enabling continuous structural health monitoring.

Keywords: Smart sensors and monitoring systems, carbon-based fillers, smart walls, structural health monitoring

References:

[1] A. D'Alessandro, H.B. Birgin, G. Cerni, F. Ubertini, Smart Infrastructure Monitoring through Self-Sensing Composite Sensors and Systems: A Study on Smart Concrete Sensors with Varying Carbon-Based Filler, Infrastructures 7 (2022) 48.

[2] W. Dong, W. Li, Z. Tao, K. Wang, Piezoresistive properties of cement-based sensors: Review and perspective, Construction and Building Materials 203 (2019) 146–163.

[3] B. Han, X. Yu, J. Ou, Self-Sensing Concrete in Smart Structures, Butterworth-Heinemann, Elsevier Inc., 2015. ISBN 978-0-12-800517-0.

MS13

Extended Classification and Generalized Vaiana-Rosati Model Accounting for Rate-Independent Hysteresis Loops with Evolving Shape

Nicolò Vaiana, **Luciano Rosati**

Department of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy

E-mail: nicolo.vaiana@unina.it

Abstract

Mechanical systems and materials may exhibit rate-independent hysteretic responses that involve generalized force-displacement hysteresis loops with varying shape. With the aim of proposing a unified phenomenological modeling approach to accurately reproduce them, we first classify such hysteresis loops into four categories according to the analytical properties of their limiting curves. Subsequently, we generalize a modeling approach, recently developed by the authors, to simulate the vast majority of experimental hysteresis loops with evolving shape. The proposed approach offers both analytical and differential formulations, allows for an uncoupled modeling of the generic loading and unloading phases by employing two distinct sets of nine parameter functions having a clear mechanical meaning, and requires a straightforward computer implementation. A meticulous model validation is carried out by adopting experimental hysteresis loops retrieved from the literature. Additionally, a numerical application is performed to show the agreement between the results provided by two solution procedures that exploit the analytical and differential formulations of the model, respectively, to analyze four different mechanical systems subjected to three types of external generalized forces.

Keywords: mechanical hysteresis, complex hysteresis loop, evolving shape

Development of Industry 4.0–Compliant IoT Gear Motors

Dr. István Gábor Gyurika

Department of Mechanical Engineering, University of Pannonia, Hungary

E-mail: gyurika.istvan.gabor@mk.uni-pannon.hu

Abstract

The vast majority of machinery and equipment utilized in manufacturing companies across all industrial sectors are powered by geared electric motors. Their scope of application is extremely broad, since they contribute to nearly every production process. Consequently, any issues associated with these drive units affect almost all industrial sectors globally. An unforeseen, abrupt malfunction of such equipment might result in significant operational disruption for a corporation. On the one hand, a malfunction may trigger secondary failures in related components, resulting in additional downtime and increased maintenance and repair expenses. The presentation outlines the first phase of a two-year research and development project. The project aims to develop an IoT-enabled gear motor that can reduce production downtime caused by workstation malfunctions. The product will be a fully integrated smart drive unit equipped with multiple sensors, a motor-integrated drive controller, and a WiFi-enabled embedded computer. The system will link to a cloud-based automatic diagnostic platform powered by artificial intelligence. This digitally revolutionary system continuously monitors the condition and the changes of the gear motor based on acquired sensor data, enabling the accurate prediction of potential failures. It offers real-time notifications to the user and provides recommendations for inspecting, maintaining, or replacing specified components. As a result, maintenance activities can be scheduled based on actual equipment status (condition-based maintenance), enabling the implementation of predictive maintenance strategies. This significantly minimizes production losses caused by unexpected breakdowns. Ultimately, the system is designed to prevent the aforementioned operational and financial losses while delivering substantial added value to users.

„Project no. 2024-1.1.1-KKV_FÓKUSZ-2024-00057 is co-funded by the NRDI Office and the National Innovation Agency with the support of the Hungarian State."

Keywords: IoT, gear motor, smart drive, prediction

Dynamic Response and Scaling Constraint Mitigation for Discrete Flexible Structures in Full-Scale Rockfall Testing

Shr-Fan Yang [a], Tomonori Tajima [b], Masakazu Namba [c], Koichi Arakawa [d] & Louis Ge [a]

[a] Department of Civil Engineering, National Taiwan University, Taipei, Taiwan
[b] RAITEKU CO.,LTD, Toyama, Japan
[c] RAITEKU CO.,LTD, Niigata, Japan
[d] RAITEKU CO.,LTD, Nagoya, Japan

E-mail: D14521010@ntu.edu.tw

Abstract
Rockfall protection systems are discrete flexible structures characterized by discontinuous slender components with large deformation capacities. Verification currently relies on costly full-scale tests per international standards such as EAD 340059-00-0106 [1]. However, budgetary constraints and complex in-situ boundary conditions often obscure the net's intrinsic dynamics. While Xu et al. [2] validated explicit dynamic analysis and Mazzariol et al. [3] demonstrated the viability of scaling with dissimilar materials, a generalized framework addressing component geometric distortion remains absent. Due to discrete commercial specifications, scaled models often fail to satisfy strict geometric similitude, causing significant response deviations. This study proposes a dynamic scaling framework for solitary netting components to address geometric distortion. We introduce a constitutive parameter tuning strategy based on Cauchy number conservation and energy consistency. A modified governing equation incorporating axial stiffness and moment of inertia is derived. By inversely adjusting Young's modulus and density via equivalent correction, the effects of distortion on strain and kinetic energies are offset. Verification was conducted using LS-DYNA solitary net model, with boundary conditions derived from full-scale experiments to simulate realistic deformation. Systematic distortion sensitivity analyses evaluated the stiffness compensation strategy under large deformation phases. Results show that uncorrected models exhibit significant deviations, failing to capture the dynamic response. However, the proposed mechanism achieves good agreement with the benchmark. This study verifies the sensitivity of discrete structures to stiffness distribution and provides a general design method for discrete beam/cable systems under constrained conditions.

Keywords: Rockfall protection systems, Dynamic Scaling Laws, Energy Consistency, Stiffness Compensation

References:

[1] European Organisation for Technical Approvals (EOTA), EAD 340059-00-0106: Falling Rock Protection Kits, EOTA, Brussels, 2018.

[2] H. Xu, C. Gentilini, Z. Yu, X. Qi, S. Zhao, An Energy Allocation Based Design Approach for Flexible Rockfall Protection Barriers, Eng. Struct. 173 (2018) 831-852.

[3] L.M. Mazzariol, R.E. Oshiro, M. Alves, A Method to Represent Impacted Structures Using Scaled Models Made of Different Materials, Int. J. Impact Eng. 90 (2016) 81-94.

Probability distribution of highly-non-Gaussian wind pressure peak factors on hyperbolic paraboloid roofs

Michele Barbato [a]

[a] Professor, Department of Civil and Environmental Engineering, University of California-Davis, Davis, CA, USA

E-mail: *mbarbato@ucdavis.edu*

Abstract

The probabilistic characterization of wind pressure peak factors presents a nontrivial challenge with direct implications for structural design. Recent investigations of hyperbolic paraboloid roof systems have demonstrated that peak factors may substantially exceed values predicted under a Gaussian process assumption [1,2]. However, peak wind pressures are commonly modeled using the Gumbel (i.e., Type I extreme value) distribution, which implies the assumption that the underlying stochastic process is Gaussian [3]. This study introduces a Type II extreme value distribution to represent the peak factors of wind pressure processes acting on hyperbolic paraboloid roofs when the underlying stochastic process exhibits pronounced non-Gaussian behavior. The proposed probabilistic model is calibrated and validated against experimentally obtained wind pressure time histories derived from boundary-layer wind tunnel testing. Results indicate that the conventional Gumbel assumption remains adequate when the underlying process is approximately Gaussian. However, for highly non-Gaussian wind pressure processes, the Type II extreme value distribution yields a markedly improved fit to the empirical peak factor data. A new probability distribution obtained as a weighted combination of Gumbel and Type II extreme value distributions is proposed for intermediate regimes characterized by mildly non-Gaussian stochastic behavior. These findings underscore the importance of explicitly accounting for non-Gaussian characteristics in extreme value modeling of wind effects.

Keywords: wind pressure; peak factor; Gaussian process; non-Gaussian process; hyperbolic paraboloid roof.

References:

[1] Rizzo F, Barbato M, Sepe V. Peak factor statistics of wind effects for hyperbolic paraboloid roofs. Eng Struct 2018;173. https://doi.org/10.1016/j.engstruct.2018.06.106.

[2] Rizzo F, Barbato M, Sepe V. Shape dependence of wind pressure peak factor statistics in hyperbolic paraboloid roofs. J Build Eng 2021;44. https://doi.org/10.1016/j.jobe.2021.103203.

[3] Huang MF, Lou W, Chan CM, Lin N, Pan X. Peak Distributions and Peak Factors of Wind-Induced Pressure Processes on Tall Buildings. J Eng Mech 2013;139:1744–56. https://doi.org/10.1061/(asce)em.1943-7889.0000616.

Contact Evolution and Multi-Directional Load Generation in Heavy-Haul Railway Couplers

Yazhao Wang [a], **Wei Zhou** [a]

[a] School of Traffic & Transportation Engineering, Central South University, Changsha, China

E-mail: yazhao_wang@csu.edu.cn

Abstract

Heavy-haul railway couplers operate under complex loading conditions involving not only longitudinal tension and compression, but also lateral shaking and vertical nodding during curve negotiation, ramp passage, and impact events. Previous studies on force-measuring couplers have demonstrated the existence of such multi-directional loads, yet the contact-mechanics origin of these load components remains insufficiently understood. In this study, a polygonal contact model is developed for the coupled coupler interface to investigate how clearance, friction, intermittent contact, and separation affect the dynamic evolution of the contact state. The model incorporates coupler gap, surface friction, and contact loss phenomena, and is combined with track geometry parameters to analyze coupler loads, coupler swing angles, active contact element evolution, and contact region migration during operation. The results show that frequent contact-separation events lead to irregular changes in the contact region within the coupled interface. The migration of the contact area is associated with the generation of lateral and vertical force components, which further contribute to the shaking and nodding motions of the coupler. These findings provide a mechanics-based interpretation for the multi-directional loads previously identified by force-measuring coupler studies and highlight the importance of contact evolution in the nonlinear dynamic behavior of articulated railway systems. The proposed framework offers a useful basis for further studies on non-smooth contact-induced dynamics and the safety assessment of heavy-haul train coupler systems.

Keywords: contact mechanics, structural dynamics, railway coupler, multi-directional loads

MS14

Timber pegged joints: reading in key new Eurocode 8

Antonio Sandoli [a] **& Carla Ceraldi** [b]

[a] Department of Biosciences and Territory, University of Molise, Campobasso, Italy
[b] Department of Structures for Engineering and Architecture, University of Naples Federico II, Naples, Italy

E-mail: *antonio.sandoli@unimol.it*

Abstract

Timber pegged joints are a consolidated technique for realizing connections in new timber framed buildings and/or for restoration of the ancient ones [1,2]. Such types of connections are traditionally adopted in low- or null- seismic regions, thus their seismic resistance did not represent an issue. On the other hand, also in the framework of enhanced sustainability provided by all-timber solutions, timber pegged joints are under development worldwide. Despite this, no detailed studies aimed at investigating the potentialities of timber pegged connections in seismic regions are available in the literature, as well as no basic seismic design rules are included in the existing Standards.

Moving from the recent experimental data collection on dowel timber joints performed by the authors in a recent work [3], this paper provides a their reading in key to new generation of the Eurocode 8 (EC8). In particular, the paper focuses on the feasibility of timber pegged joints into matching and aligning the hierarchy of strength rules provided by EC8 for steel dowel bearing connections to timber pegged ones; in such a way, first insights on basic seismic design rules of timber pegged connection - now unavailable in the new EC8 - are discussed. The available dataset allowed to define suitable ductility classes and hierarchy of strength factors for timber pegged joints in accordance with the general framework of the new EC8. The achieved results demonstrated the applicability of the rules envisaged by EC8 to these types of connections, representing a good starting point for future investigations from both experimental and numerical standpoint.

Keywords: Timber pegged joints, Eurocode 8, Seismic design rules.

References:

[1] R.J. Schmidt. Timber pegs – Considerations for mortise and tenon joint design. Struct. Magazine (2006) 3: 44-47.

[2] G. Ruam, G.H. Filz, G. Fink. Shear capacity of timber-to-timber connections using wooden nails, Wood Mat. Sc. & Eng. (2021) 17(1): 20-29.

[3] A. Sandoli, C. Ceraldi, A. Prota. Feasibility of timber pegged joints for seismic design of Structures, J. Struct. Engineering (2023)149(5): 04023043.

Experimental assessment and modelling of creep in Laminated Veneer Lumber (LVL)

Mohsen Naghdinasab [a], **Jan T. Benthien** [b], **Sabrina Heldner** [b], **Martin Nopens** [b], **Philippe Grönquist** [a,c]

[a] Materials Testing Institute (MPA), University of Stuttgart, Stuttgart, Germany
[b] Thünen-Institute of Wood Research, Hamburg, Germany
[c] Institute of Construction Materials, University of Stuttgart

E-mail: Mohsen.Naghdinasab@mpa.uni-stuttgart.de

Abstract

Laminated Veneer Lumber (LVL) is being increasingly employed in structural applications where long-term performance under sustained loading affects serviceability requirements. Current standard creep factors of LVL (e.g., k_{def} according to Eurocode 5 [1]) place it in the same creep magnitude classes as solid or glued solid timber products. However, due to its specific production steps involving, e.g., steam treatment and rotary peeling, LVL has an inherently different structure. Nevertheless, a reliable experimental basis of creep experiments for LVL is largely missing. In this study, the creep behavior of small-scale LVL specimens made from European beech (*Fagus sylvatica*) and Scots pine (*Pinus sylvestris*) is investigated through a combination of experimental testing and finite element (FE) modelling. Creep curves are obtained from time-dependent deflection measurements of LVL specimens subjected to constant bending loads under both constant and varying climate conditions. Reference creep curves for solid beech and pine are provided for comparison. FE modeling is used to investigate the structure-property-related behavior of LVL, in which viscoelastic and mechano-sorptive creep mechanisms are incorporated, allowing the representation of time-related effects on stress and strain development, and especially, to capture the difference in creep behavior of LVL compared to solid wood.

Keywords: Timber engineering, Laminated Veneer Lumber (LVL), Creep behavior, Wood Science and Technology

References:

[1] 'EN 1995-1-1, "Eurocode 5: Design of timber structures – Part 1-1: General Common rules and rules for buildings," European Committee for Standardization (CEN), Brussels, Belgium, with corrections and amendments + AC:2006, A1:2008, and A2:2014'.

Deployable Timber–Cable Roof Structures for Solar-Active Stadiums

Rana Nazifi Charandabi [a,b], Gerardo Carpentieri [b], Ada Amendola [b], Fernando Fraternali [b]

[a]Department of Information Engineering, Electrical Engineering and Applied Mathematics, University of Salerno, Fisciano (SA), Italy

[b] Department of Civil Engineering, University of Salerno, Fisciano (SA), Italy

E-mail: rnazificharandabi@unisa.it

Abstract

This paper presents a reconfigurable roof system for sports stadiums that merges structural adaptability with on-site renewable energy generation. The proposed solution targets large-span enclosures and is based on a spatial arrangement of engineered timber members coupled with a very limited number of steel cables, forming a prestressed three-dimensional system with reduced material demand and a low environmental footprint. Glued laminated timber components serve as the primary load-bearing elements, while steel tendons govern the overall geometry and allow the global stiffness to be adjusted through controlled prestressing. The roofing concept relies on a compliant membrane integrating lightweight bifacial photovoltaic modules, enabling both significant geometric transformations and continuous solar energy capture. A coherent design methodology is described, including mass-based dimensioning of structural elements and the definition of an efficient prestressing scheme for a representative mast–roof assembly. The structural performance under wind actions is investigated through nonlinear equilibrium tracking methods that account for follower-force effects and provide insight into stability limits and dynamic behavior. These studies are complemented by three-dimensional finite element analyses of a modular portion of the stadium, used to assess spatial response and transverse vibration modes. The results confirm that the proposed deployable timber–cable system achieves adequate stiffness, stability, and dynamic performance, supporting its applicability to sustainable, solar-integrated stadium infrastructures.

Keywords: Tensegrity, Timber structures, Solar roofs, Deployability

References:

[1] Nazifi Charandabi, R, Carpentieri, G., Fraternali, F. , Mechanical response of an adaptive solar timber stadium structure, Mech. Adv. Mater. Struct. (2025) In press (doi: 10.1080/15376494.2026.2644538).

[2] Nazifi Charandabi, R, de Castro Motta, J., Carpentieri, G., Babilio, E., Bo, J. B., Fantuzzi, N., Fraternali, F. , Deployability, Mechanical Response, and Energy Harvesting Capacity of a Novel Solar Roof For Sports Stadiums, Dev. Built Environ. (2025) 100771.

[3] Nazifi Charandabi, R., Babilio, E., Carpentieri, G., Spagnuolo, G., Amendola, A., Fraternali, F., A Tensegrity Structure for a Solar Stadium Roof with Sun-Tracking Capability, Thin-Walled Struct., 210, (2025) 113033.

MS15

Applicability of Traditional Concrete Creep Model in Modern Concrete

Qing Wang [a], Xingyue Li [a]

[a] School of Civil Engineering and Transportation, Guangzhou University, Guangzhou 510006, China

E-mail: wangq@gzhu.edu.cn

Abstract

Concrete creep is a critical factor affecting the long-term performance of structures. Accurate prediction of creep deformation is of great significance for the life-cycle safety assurance of engineering projects. Present study systematically reviews the theoretical evolution of creep prediction models, from the empirical regression-based ACI 209, the semi-empirical semi- theoretical CEB-FIP (fib), to the solidification theory-based B3/B4 series. Theoretical foundations, parameter characteristics, and applicable scopes of each model were revealed. The predictive performance of classical models for different materials is comprehensively evaluated for Ultra-High Performance Concrete (UHPC), High-Strength Lightweight Concrete (HSLC), High-Strength Concrete Filled Steel Tube (HSCFST) and Recycled Ceramic Aggregate Concrete Filled Steel Tube (RCCACFST). Results indicate that the creep coefficient of UHPC ranges from 0.6 to 1.5, which is generally overestimated by ACI 209 and fib models, while B4 model demonstrates higher prediction accuracy due to its consideration of the hydration rate parameter. The specific creep of HSLC is less than 20 με/MPa, and fib model becomes the most suitable prediction model owing to its density correction consideration. The creep coefficient of HSCFST is reduced by more than 50% compared to plain concrete, and the modified ACI 209 model achieves optimal prediction by introducing a strength correction factor. The creep coefficient of RCCACFST is reduced by 7.4%-18.8%, and modified ACI 209-W model with correction of water absorption achieves less than 5.9%. Furthermore, the causes of significant model errors were analyzed based on the mismatch of raw material or mix proportion, the differences in microstructure and the effects of multiple coupling conditions. Corrections were conducted including equivalent age, density and water amount. Summarize of concrete creep model can provide theoretical basis and model selection for analyzing the creep effect of structures with modern concrete.

Keywords: Creep; Modern concrete; Prediction model; Applicability; Modification

Linking particle micromechanics to multiscale morphologies during granular creep via In-Situ X-Ray CT

Jianwei Cheng, Zhengjin Wang, Shaoqi Huang, Chongpu Zhai & Minglong Xu

State Key Laboratory for Strength and Vibration of Mechanical Structure, School of Aerospace Engineering (School of Aerospace Engineering, Xi'an Jiaotong University, Xi'an 710049, China)

E-mail: zhaichongpu@xjtu.edu.cn

Abstract

Granular media is among the most pervasive engineering solids, spanning natural soils to industrial powders. Unlike idealized elastic–plastic continua, a granular skeleton subjected to sustained stress undergoes a subtle but continuous evolution. This slow dynamics is central to the long-term reliability of granular assemblies. We investigate how multi-level particle morphology influences the granular micromechanics of packings undergoing low-stress creep. Four distinct granular assemblies are fabricated via high-precision 3D printing, with their multiscale geometric features systematically controlled through spherical harmonics. Advanced in-Situ X-ray micro-CT is employed with sequential measurements over extended durations to track the evolutionary micromechanics of Lagrangian particle sets within the specimen core. Based on 3D reconstructed digital imagery, we comprehensively quantify individual particle translations and rotations, the kinematic evolution of the contact network, and equivalent particle strains, along with their underlying statistical distributions. The experimental results demonstrate that elevated particle irregularity significantly accelerates macroscopic creep deformation, accompanied by pronounced fluctuations in coordination number, packing porosity, and highly localized structural rearrangements. Micro-scale correlation analysis reveals that enhanced surface roughness/morphology drives significant fluctuations in the local packing architecture, void fabric, and contact fabric, while showing a weaker correlation with global particle shape parameters. Crucially, while relative particle translations and equivalent strains are strongly dictated by surface morphology, relative particle rotations are predominantly governed by overall particle shape. These findings support a pathway-specific division of contribution in creep, where particle shape primarily modulates rotational kinematics and surface morphology governs contact reorganization and fabric evolution. This work provides a framework for bridging the gap between grain-scale morphology and macroscopic time-dependent granular mechanics, offering vital guidelines for shape-aware constitutive modeling of granular media.

Keywords: Particle micromechanics, Multiscale morphologies, Granular creep.

References:

[1] P. Tahmasebi, A state-of-the-art review of experimental and computational studies of granular materials: Properties, advances, challenges, and future directions, Progress in Materials Science 138 (2023) 101157. https://doi.org/10.1016/j.pmatsci.2023.101157.

[2] D. Yang, X. Chu, Influence of particle shape on creep and stress relaxation behaviors of granular materials based on DEM, Computers and Geotechnics 166 (2024) 105941. https://doi.org/10.1016/j.compgeo.2023.105941.

Application of Genetic Algorithms to the Biaxial Design Optimization of T- Shaped Reinforced Concrete Walls

Felipe Yáñez [a], Fabián Rojas [a] & Leonardo Massone [a]

[a] Department of Civil Engineering, University of Chile, Santiago, Chile

E-mail: *felipe.yanez.v@ug.uchile.cl*

Reinforced concrete (RC) wall systems are widely used in high seismic regions due to their robustness, material availability, and effective seismic performance. However, recent earthquakes in Chile and New Zealand have exposed critical vulnerabilities in wall boundary elements, particularly premature longitudinal bar buckling and brittle concrete crushing under combined high axial loads with flexural loads. Traditional design methodologies often simplify complex transversal wall geometries by dividing them into independent rectangular sections and assuming unidirectional responses aligned with principal structural directions. This approach produces overly conservative, costly, and potentially fragile designs. New techniques have emerged in recent years, particularly evolutionary algorithms (EA), to address such challenges. These optimization techniques, inspired by natural selection and biological evolution, rely on iterative selection, mutation, and crossover to progressively improve a population of candidate solutions. Genetic algorithms (GA), a subset of EA, encode potential solutions as "chromosomes," evaluate their performance using a fitness function, and evolve improved solutions over successive generations. Unlike traditional analytical procedures, GA can efficiently explore highly nonlinear, multivariable design spaces while simultaneously enforcing geometric and code-based constraints, making them particularly suitable for optimizing non- rectangular RC wall sections subjected to biaxial demands. This study evaluates the applicability of genetic algorithms to optimize longitudinal reinforcement in the boundary elements of T-shaped RC walls. The proposed reinforcement layouts comply with Chilean codes. These configurations were compared with conventional design solutions. Preliminary results demonstrate the strong potential of genetic algorithms to produce structurally efficient and cost-effective reinforcement layouts, showing promise for enhancing design strategies in more complex RC wall systems.

Keywords: Genetic algorithms, reinforced concrete walls, biaxial interaction, seismic design

MS16

In-situ X-ray Computed Tomography Characterization of Auxetic Cementitious Composites

Zhaozheng Meng and Branko Šavija

Microlab, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands

E-mail: z.meng@tudelft.nl

Abstract

Concrete is inherently brittle and requires reinforcement to improve its deformation capacity. Auxetic lattices with a negative Poisson's ratio have been regarded as a promising reinforcement due to their lateral contraction under compression, which provides confinement to the surrounding cement matrix. However, the underlying composite interaction mechanisms between the auxetic lattice and cement matrix remain insufficiently understood. Previous studies relying on ex-situ X-ray computed tomography (CT) are limited in capturing the true failure state, as crack closure and stress relaxation may occur during unloading and scanning, obscuring the actual damage evolution[1]. To overcome this limitation, this study employed dynamic in-situ X-ray computed tomography (CT) combined with digital volume correlation (DVC) to capture the real-time failure processes of auxetic cementitious composites. The results demonstrate that auxetic cementitious composites exhibit markedly enhanced post-peak ductility compared with the unreinforced reference. The full-field strain distribution from DVC analysis indicates a clear confinement effect over inner side cement matrix from the auxetic lattice reinforcement. More importantly, lattice architecture plays a critical role in confinement efficiency. Shell-type auxetic structures exhibit reduced interfacial debonding and maintain stronger composite action with cement matrix, resulting in higher strength and more stable softening behavior than strut-type counterparts. Real-time imaging reveals a fundamental shift in failure mode: the shell-type auxetic lattices promote dispersed damage evolution, whereas the strut-type auxetic tends to induce localized cracking in uncovered regions. By directly visualizing failure process through in-situ CT, this work highlights the importance of balancing active confinement with interfacial integrity in cementitious composites. The findings advance the broader concept of integrating mechanical metamaterials with brittle matrices to achieve mechanical enhancement, offering potential for the development of next generation of resilient and functional construction materials.

Keywords: Micromechanics, Cementitious composites, Auxetic, In-situ CT

References:

[1] Z. Meng, Y. Xu, J. Xie, W. Zhou, R.J.M. Bol, Q.-f. Liu, & B. Šavija, Unraveling the reinforcing mechanisms for cementitious composites with 3D printed multidirectional auxetic lattices using X-ray computed tomography, Materials & Design 246 (2024) 113331.

“Bio-metals” – ancient biological materials with nano-indentation size effects: Experiments and elements of manifold micromechanics

Luis Zelaya-Lainez [a], Friedrich S. Schuster [a], Stefan Manhartseder [a], Maximilian Landegger [a], Kyojiro N. Ikeda [b], Florian Raible [b], Olaf Lahayne [a], Stefan Scheiner [a] & Christian Hellmich [a]

[a] Institute for Mechanics of Materials and Structures, TU Wien, Vienna, Austria
[b] Department of Neurosciences and Developmental Biology, University of Vienna, Vienna,

Austria

E-mail: *christian.hellmich@tuwien.ac.at*

Abstract

The Nix-Gao nanoindentation size effect [1] – according to which the square of hardness varies inversely with indentation depth – is widely recognized as a defining feature of crystalline metals and is commonly attributed to the accumulation of dislocations, i.e., line-type defects within the atomic lattice. Recent work has demonstrated that an analogous behavior appears in a fundamentally different material class: metal-coordinated proteins forming the jaws of several bristle worm species [2]. Building on this finding, the present study provides a systematic analysis of the jaw midplane (rather than the surface) of *Perinereis cultrifera*. Nanoindentation experiments were conducted at six indentation depths across eleven selected locations spanning both the central and tip regions of the jaw. For both regions, the measured hardness–depth relationships follow the Nix-Gao scaling law typically associated with strain-gradient plasticity. In addition, the experiments indicate the presence of an elastic size effect. This observation is interpreted using concepts from manifold micromechanics: localized microscopic volume forces of Peach-Koehler type [3], acting at dislocation-like folds within the ion-coordinated protein network, generate significant macroscopic strain gradients at the scale of a representative volume element of the ion-reinforced protein matrix.

Because these ancient biological materials combine polymer-like and metallic characteristics in an unusual manner, we propose the term bio-metals and consider them a promising emerging topic in biophysics and bioengineering.

Keywords: Nix-Gao size effect, bristle worm, nanoindentation, manifold micromechanics

References:

[1] W.D. Gao and H. Gao, Indentation size effects in crystalline materials: a law for strain gradient plasticity, J. Mech. Phys. Solids 46 (1998) 411-425.

[2] L. Zelaya-Lainez, G. Balduzzi, O. Lahayne, K.N. Ikeda, F. Raible, C. Herzig, W. Nischkauer, A. Limbeck, C. Hellmich, Jaws of Platynereis dumerilii: Miniature biogenic structures with hardness properties similar to those of crystalline metals, JOM 73 (2021) 2390-2402.

[3] M. Peach and J.S. Koehler, The forces exerted on dislocations and the stress fields produced by them, Phys. Rev. 80 (1950), 436-439.

Time-Resolved Neutron Tomography of Biochar-Internal Curing in Cement Paste

Liang Chen, Kemal Celik

1 Division of Engineering, New York University Abu Dhabi, Abu Dhabi 129188, United Arab Emirates

Email: kemal.celik@nyu.edu

Abstract

Concrete is the second-most-consumed material on Earth, and moisture transport in cementitious systems critically governs durability and structural health. Biochar, a porous carbon material produced from waste biomass under oxygen-limited pyrolysis, has been recognized as a promising carbon-sequestration pathway and a potential internal curing agent for low-carbon concrete. Although biochar has been shown to enhance hydration and mitigate shrinkage, quantifying the migration of internal curing water remains difficult with conventional techniques. In this study, time-resolved neutron tomography was employed to directly visualize and quantify water redistribution in cement paste incorporating engineered biochar particles produced at 650 °C under dry and pre-wetted conditions. Sequential in-situ scans were performed from 18 min to 15.9 h after mixing. Calibrated attenuation datasets were registered and analyzed through voxel-wise subtraction. X-ray tomography (XCT) provided accurate biochar geometry for concentric radial analysis. A characteristic release time and a time-weighted radial moisture enhancement metric were introduced to evaluate release kinetics and the effective internal curing zone. Results demonstrate distinct release behaviors governed by initial moisture state and pyrolysis temperature. The combined neutron–XCT framework establishes a quantitative basis for assessing biochar internal curing in low-carbon cement systems.

Keywords: neutron tomography; biochar; internal curing; moisture transport

Multiscale modeling of basic creep of mature slag-based CEM II concrete

Maximilian Sorgner [a], **Rodrigo Díaz Flores** [a], **Bernhard Pichler** [a], **Thomas Pilgerstorfer** [b], **Bernd Moritz** [c] **& Christian Hellmich** [a]

[a] TU Wien (Institute for Mechanics of Materials and Structures, TU Wien, Vienna, Austria)
[b] Geoconsult ZT GmbH (Puch bei Hallein, Austria)
[c] ÖBB Infrastruktur AG (Graz, Austria)

E-mail: *maximilian.sorgner@tuwien.ac.at*

Abstract

The demand for accurate characterization of concrete made from slag-based CEM II cement is becoming increasingly important, as the construction sector shifts towards eco-efficient materials to reduce the environmental impact of cement production. In the present contribution, the basic creep behavior of mature slag-based CEM II concretes is identified from classical macroscopic creep tests, and traced back to mixture-invariant characteristics of the hydrates, by means of an adaption of an experimentally validated three-step micro-viscoelastic model for CEM I/OPC-concretes. The model is complemented by a Powers-Acker-type hydration model for CEM II and an isochoric creep function for the CEM II hydrates. The creep function accounts for (i) short- to long-term creep, (ii) the decrease in hydrate stiffness moduli with increasing temperature, and (iii) the increase in the hydrate shear creep modulus with decreasing relative humidity. Aging effects resulting from ongoing hydration during creep testing are considered by means of a strain rate-based viscoelastic analysis. Downscaling of mechanical properties from the concrete level to the scale of the hydrates evidences a shear creep compliance of CEM II hydrates that is twice as large as the one of CEM I hydrates. Thus, hydrates made from slag-based CEM II exhibit a much more pronounced creep activity than CEM I hydrates. This can be explained by pozzolanic hydration reactions of slag, where non-creeping portlandite is consumed, leading to the production of additional, creep-active, calcium silicate hydrates (C-S-H). The increased amount of creep-active C-S-H in the hydrates of CEM II materials leads to increased creep. This results in a more pronounced creep compliance of slag-based CEM II concrete, compared to concrete made from CEM I. It is concluded, that slag-based CEM II concretes are especially suitable for structures under displacement-controlled conditions, because the larger creep-activation readily implies a faster relaxation of stresses.

Keywords: basic creep, slag-based CEM II hydrates, micromechanics, long-term creep

Testing mechanical and transport properties of ITZ in Concrete

Erik Schlangen [1], Shan He, Magdalena Rajczakowska, Kangtai Yan, Arpan Adhikari and Branko Savija

[1] Microlab, CMD-CEG, TU-Delft, Delft, The Netherlands,

Email: erik.schlangen@tudelft.nl

Abstract

In the project MAGICON we propose a completely new philosophy for developing and designing concrete. We aim to conceptualize a strategy based on materials genome engineering that combines Experimental tools, Computational tools and Digital data. The MAGICON philosophy should make it possible to select and combine ingredients for concrete that result in optimized properties and behaviour. The need for reinventing concrete comes from the urge to use greener and more environmental friendly binder systems and alternative aggregate particles mainly from recycled materials to work towards a circular economy. The quality and, short and long term performance of concrete is governed by the interplay of binder and aggregates. Especially the connection between both, called Interfacial Transition Zone (ITZ), determines mechanical and transport properties of the composite. The ITZ is actually the finger print of the material and forms the basis in the MAGICON framework to redesign new concretes. To be able to characterize the ITZ and incorporate the results in the design philosophy the several challenges should be overcome. Two of these challenges will be addressed in this paper:

- Development of a method to produce small scale samples including particles, matrix and ITZ which are representative for the composite, including its eigenstresses that are always present in all the phases.
- Development of testing techniques for measuring mechanical and transport properties and the combined effect of mechanics and transport on the small scale samples.

Keywords: Experimental Mechanics, Micro-Nano-scale, Mechanical Testing, Transport Testing

Image-Guided Identification of Phase-Intrinsic Nanoindentation Properties in Alkali-Activated Slag–Fly Ash Binders

Markus Königsberger [a,b], Luis Zelaya-Lainez [a], Olaf Lahayne [a], Bernhard L. A. Pichler [a] & Christian Hellmich [a]

[a] Institute for Mechanics of Materials and Structures, TU Wien, Vienna, Austria
[b] Université libre de Bruxelles, Brussels, Belgium

E-mail: luis.zelaya@tuwien.ac.at

Abstract

Alkali-activated materials (AAMs) that have slag and fly ash as constituents exhibit a high stiffness and hardness contrasts between unreacted precursor particles and the surrounding C-(N-)A-S-H gel. To identify each the mechanical properties intrinsic of each phase from grid nanoindentation is extremely challenged by boundary effects inherent to composite half-spaces. This study presents an image-guided nanoindentation protocol combining ultra-smooth surface polishing (Rq = 16 nm), a large indentation grid campaign (2178 indents at 60 nm depth), and microscopy-based identification maps [1]. Indentation properties are correlated with the minimum distance to phase boundaries. This enables a systematic removal of mixed volume responses. Plateau/constant values reached at sufficient boundary distances yield intrinsic elastic moduli of around 96 GPa for slag and around 11.8 GPa for C-(N-)A-S-H gel. Finally, a micromechanical upscaling via Hashin–Shtrikman bounds confirms consistency with independently measured ultrasonic wave velocities of the macroscopic paste. Upon further analysis we encountered that the indentation-probed elastic domain extends up to approximately 130 times the contact depth, significantly exceeding classical half-space assumptions. The proposed methodology provides a robust framework for resolving phase-specific micromechanics in highly heterogeneous cementitious binders.

Keywords: Oliver-Pharr-half-spaces, alkali-activated materials, nanoindentation, micromechanics

References:

[1] M. Königsberger, L. Zelaya-Lainez, O. Lahayne, B.L.A. Pichler, C. Hellmich, Nanoindentation-Probed Oliver-Pharr Half-Spaces in Alkali-Activated Slag-Fly Ash Pastes: Multimethod Identification of Microelasticity and Hardness, Mech. Adv. Mater. Struct. 29 (2022) 4878–4889.

Distance-guided nanoindentation reveals mechanical changes of cell wall layers in native, infiltrated, and trans- parent wood

Johanna Schindler [a], **Markus Königsberger** [a], **Luis Zelaya-Lainez** [a] **& Josef Füssl** [a]

[a] Institute for Mechanics of Materials and Structures, TU Wien, Vienna Austria

E-mail: johanna.schindler@tuwien.ac.at

Abstract

Transparent wood is a promising material that combines optical transparency with the mechanical stability of cellulose reinforcement. It is produced by delignifying native wood and infiltrating the resulting porous structure with a refractive-index-matched acrylic polymer, minimizing light scattering and forming a transparent, cellulose-reinforced composite [1]. While the macroscopic mechanical properties of transparent wood have been widely studied [2], the effects of individual chemical modification steps on the micromechanical properties of wood cell wall components remain unexplored. This study addresses this gap by analysing the micro- mechanical properties of the S2-layer and middle lamella using nanoindentation. Shallow inden- tation depths combined with a distance-guided evaluation approach were used to distinguish the responses of different cell wall regions and minimize the influence of neighbouring phases. Three material states were investigated, native birch (NB), polymer-infiltrated native birch (NB-HEMA), and delignified, polymer-infiltrated birch (DB-HEMA). Nanoindentation experiments were performed at a displacement-controlled depth of 50 nm on ultra-smooth surfaces prepared by diamond knife ultramicrotomy. S2-layer stiffness increased from 19,5 GPa in NB to 21,0 GPa in NB-HEMA and 22,4 GPa in DB-HEMA, demonstrating that polymer infiltration enhances stiffness, with delignification further improving performance. Hardness showed minor variations, reflecting the dominant role of the polymeric matrix and the limited contribution of cellulose along the indentation direction.

Keywords: Wood Modification, Nanoindentation, Micromechanical Properties

Acknowledgments: The AI-TranspWood project, HORIZON-CL4–2023-RESILIENCE- 01–23 (Grant Agreement 101138191), is gratefully acknowledged. This project is co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them.

References:

[1] Y. Li, E. Vasileva, I. Sychugov, S. Popov, and L. Berglund, "Optically Transparent Wood: Recent Progress, Opportunities, and Challenges," *Advanced Optical Materials*, vol. 6, no. 14, p. 1800059, 2018, doi: 10.1002/adom.201800059.

[2] E. Jungstedt, C. Montanari, S. Östlund, and L. Berglund, "Mechanical properties of transparent high strength biocomposites from delignified wood veneer," *Composites Part A: Applied Science and Manufacturing*, vol. 133, p. 105853, Jun. 2020, doi: 10.1016/j.compositesa.2020.105853.

Effect of Precipitation Agent on Hydrated Magnesium Carbonate Formation and Strength Development in Brine-Derived Brucite

Inderjeet Singh [a], **Xiangyu Wang** [a], **Padmaja Krishnan** [a,b], **Ribal Jabbour** [c], **Asif Equbal** [c], **Kemal Celik** [a]

[a] Division of Engineering, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
[b] Department of Civil and Environmental Engineering, College of Engineering, Michigan State University, Michigan, United States of America
[c] Department of Chemistry, New York University Abu Dhabi, Abu Dhabi, United Arab Emirates
E-mail: kemal.celik@nyu.edu

Abstract

Magnesium-based binders are increasingly investigated as sustainable alternatives to conventional cement due to their ability to sequester CO_2 through carbonation. While magnesium carbonate cement systems rely on reactive MgO produced via calcination of magnesite ($MgCO_3$), the direct use of brucite ($Mg(OH)_2$) provides a lower-energy and potentially more sustainable pathway by eliminating the need for calcination. In addition, recovering magnesium from desalination brine offers an attractive approach for resource recovery and promotes the development of circular, low-carbon construction materials. In this study, brucite was directly recovered from desalination brine using two precipitation routes based on CaO and NaOH as precipitating agents. The influence of the precipitation route on the microstructure, phase evolution, and carbonation-induced strength development of the resulting binders was systematically investigated. Microstructural characterization revealed clear differences in morphology and phase composition between the CaO- and NaOH-precipitated brucite, which significantly affected their carbonation behavior. Carbonation curing promoted the formation of both crystalline and amorphous hydrated magnesium carbonate (HMC) phases. Variations in the type and relative abundance of these phases were observed between the two brucite systems, highlighting how the precipitation agent can influence the carbonation pathway and, consequently, the mechanical performance of the binder. To comprehensively identify and differentiate the formed HMC phases, advanced and conventional characterization techniques were employed, including synchrotron-based X-ray Absorption Fine Structure (XAFS) spectroscopy at the SESAME Synchrotron facility, solid-state nuclear magnetic resonance (ssNMR), scanning electron microscopy (SEM), thermogravimetric and differential thermal analysis (TGA/DTG), X-ray diffraction (XRD), and Raman spectroscopy. The combined approach provided insight into the local coordination environment of magnesium, phase composition, and microstructural evolution. Understanding the effects of precipitation route on phase evolution and strength development will aid in designing optimized brine-derived brucite binders for sustainable, low-carbon construction applications.

Keywords: Desalination brine, precipitating agent, hydrated magnesium carbonates, compressive strength development

MS17

Improving Physics-Informed Neural Networks for Structural Dynamics via Mixed Lagrangian Formalism

Yixuan Zhang [a], Haolin Li [b] & Christian Málaga-Chuquitaype [a]

[a] Department of Civil and Environmental Engineering, Imperial College London, UK
[b] Department of Aeronautics, Imperial College London, UK

E-mail: c.malaga@imperial.ac.uk

Abstract

Physics-informed neural networks (PINNs) provide a flexible framework for solving partial differential equations by embedding governing equations directly into their training. Compared to traditional numerical methods, PINNs are mesh-free, can naturally handle incomplete or measured data, support inverse problems and surrogate modelling, and can efficiently leverage parallel computation on modern hardware. These features make them attractive for structural dynamics, where simulating complex or nonlinear systems is computationally expensive. However, unlike many stationary PDE problems, dynamic problems, which are governed by hyperbolic differential equations, are explicitly time-dependent. Solving this type of problem via a global optimization over the entire time domain introduces significant challenges. In particular, PINNs with physical loss formulated using conventional representations of the equations of motion representations exhibit slow convergence and limited accuracy in predicting full response histories, even when initial conditions are strictly enforced. To overcome these limitations, we introduce a Mixed Lagrangian Formalism (MLF) as an alternative set of governing equations for the physical loss formulation. By incorporating both global degrees of freedom and local elemental forces into the system state space, the MLF-based PINN substantially strengthens the constraints imposed by the physics-informed loss. Furthermore, an integrated MLF formulation is shown to improve stability when predicting non smooth behaviours, such as sudden contact and material yielding. Numerical experiments are conducted on both single- and multi-degree-of-freedom systems. A systematic comparison is performed among PINNs constructed using the conventional formulation of the equation of motion, the state-space formulation, the MLF, and the integrated MLF. The results consistently demonstrate that MLF-based PINNs converge faster and deliver superior accuracy across all test cases. These findings emphasize the importance of selecting appropriate governing equations for loss formulation and indicate that the MLF offers a reliable and effective framework for improving the performance of PINNs in structural dynamic prediction.

Keywords: Physics-Informed Neural Networks, Structural Dynamics, Mixed Lagrangian Formalism

Rapid Seismic Wave Propagation using Deep Learning Surrogates based on Tensorized Fourier Neural Operator (T-FNO)

Marco Migliavacca[a], **Luca Brambilla**[a], **Luca Rosafalco**[a], **Chiara Smerzini**[a] **& Attilio Frangi**[a]

[a] Department of Civil and Environmental Engineering, Politecnico di Milano, Milano, Italy

E-mail: marco.migliavacca@polimi.it

Abstract

Numerical simulation of seismic wave propagation is essential for designing structures in high seismic hazard areas and assessing ground motion for risk evaluation. High-fidelity solvers, such as the spectral element code SPEED [1] developed at Politecnico di Milano, provide excellent accuracy and scalability, but large domains, high frequency resolution and heterogeneous media make computations costly. Uncertainties in seismic source parameters, such as hypocenter, fault geometry and activation, further require multiple scenario simulations, resulting in runtimes incompatible with near-real-time applications. To overcome these limitations, we develop a Deep Learning (DL) surrogate for rapid seismic response estimation. We focus on Neural Operators, particularly the Tensorized Fourier Neural Operator [2], which learns mappings between function spaces and generalizes across spatial and temporal resolutions (zero-shot super-resolution). Trained on SPEED-generated datasets, the model can approximate seismic wavefields with near-instantaneous inference times. Emphasis will be put on temporal dynamics to reproduce accurate time-histories over the whole computational domain. A key goal of this work is to provide a benchmark dataset for the seismic DL community [3], enabling the development and testing of new DL architectures specifically tailored to seismic applications. The surrogate is validated on problems with strong temporal dependence and increasing complexity, from two- dimensional plane waves in homogeneous and layered media, to point sources with dissipation and finally to fully three-dimensional domains with complex topography and extended faults. Results demonstrate that the model accurately captures both the spatial and temporal evolution of seismic wavefields, providing a scalable, data-driven framework for rapid and reliable seismic response prediction. Once trained in high-risk regions, the surrogate can deliver near- instantaneous, time-resolved forecasts to support emergency response and mitigation efforts.

Keywords: Seismic wave propagation, Deep Learning, Temporal dynamics, Tensorized Fourier Neural Operator (T-FNO)

References:

[1] I. Mazzieri, M. Stupazzini, R. Guidotti, e C. Smerzini, SPEED: SPectral Elements in Elastodynamics with Discontinuous Galerkin: a non-conforming approach for 3D multi-scale problems, *International Journal for Numerical Methods in Engineering*, vol. 95, fasc. 12, pp. 991–1010, 2013, doi: 10.1002/nme.4532.

[2] J. Kossaifi, N. Kovachki, e K. Azizzadenesheli, Multi-Grid Tensorized Fourier Neural Operator for High-Resolution PDEs, 2025.

[3] F. Lehmann, F. Gatti, M. Bertin, e D. Clouteau, 3D elastic wave propagation with a Factorized Fourier Neural Operator (F-FNO), *Computer Methods in Applied Mechanics and Engineering*, vol. 420, p. 116718, feb. 2024, doi: 10.1016/j.cma.2023.116718.

Interpretable Physics-Informed Deep Learning for the Seismic Assessment of Rigid Rocking Response

Shirley Shen [a], Christian Málaga-Chuquitaype[a]

[a] Department of Civil and Environmental Engineering, Imperial College London, London, UK

E-mail: yu.shen21@imperial.ac.uk

Abstract

As computational structural dynamics transitions toward autonomous health monitoring and rapid seismic assessment, the "black-box" nature of deep learning remains a primary barrier to engineering adoption. This research advances the state-of-the-art by proposing a Hybrid Physics-Informed Neural Network (Hybrid PINN) specifically engineered to navigate the non-smooth manifold of rocking structures. Unlike standard surrogate models, our architecture embeds the second-order differential equations of motion directly into the neural network's loss function. This enables the model to simultaneously satisfy conservation laws while correcting for unmodeled experimental uncertainties, such as stochastic impact damping and imperfect contact interfaces, using high-fidelity shaking table data. To ensure the model's predictions align strictly with mechanical principles, we implement a multi-faceted Explainable AI (XAI) protocol using SHAP and LIME to audit the network's internal logic. The analysis reveals that the Hybrid PINN autonomously identifies the slenderness ratio and restoration coefficients as the primary drivers of stability, mirroring classical analytical solutions. Validation against non-overturning experimental records demonstrates superior generalization capabilities compared to purely data-driven methods. The results prove that integrating domain-specific mechanical constraints with explainability tools creates a robust, "physics-transparent" framework essential for the next generation of earthquake-resilient design.

Keywords: Physics-Informed Neural Networks, Computational Structural Dynamics, Seismic Response Prediction, Rocking Structures, Experimental Data, Explainable AI

MS18

Structural Health Monitoring of Buildings in the Phlegraean area under volcanic Seismic Excitations

Daniela De Gregorio[a,b], Domenico Patanè[c], Claudio Martino[d], Francesca L. Perelli[a,b], Salvatore Sessa[a,b]

[a] Dep. of Structures for Engineering and Architecture, University of Naples Federico II, Napoli, Italy
[b] PLINIVS Study Centre, University of Naples Federico II, Napoli, Italy
[c] Osservatorio Etneo, Istituto Nazionale di Geofisica e Vulcanologia INGV, Catania, Italy
[d] Osservatorio Vesuviano, Istituto Nazionale di Geofisica e Vulcanologia INGV, Napoli, Italy

E-mail: salvatore.sessa2@unina.it

Abstract
The renewed bradyseismic activity affecting the Phlegraean Fields in Southern Italy has been accompanied by frequent low-to-moderate magnitude seismic events with characteristics markedly different from those of tectonic earthquakes, in terms of frequency content, duration, and recurrence [1]. In this context, traditional seismic assessment and monitoring strategies face significant limitations, especially for ordinary buildings characterized by scarce structural documentation and high epistemic uncertainty. This work presents an ongoing research activity focused on vibration-based Structural Health Monitoring (SHM) of selected pilot buildings located in the Phlegraean Fields. The monitoring system relies on independent medium-cost, high-quality accelerometric units installed at the foundation level and at the roof level of the structures, enabling continuous recording of both ambient vibrations and seismic responses induced by bradyseismic activity. Given the limited availability of detailed structural models, building characterization is performed through a statistical approach based on a large-scale database comprising approximately 9,000 buildings surveyed using the PLINIVS rapid visual assessment forms [2]. This information is used to constrain the expected structural typologies and dynamic properties, supporting the interpretation of recorded signals. The proposed SHM framework aims to track the temporal evolution of dynamic response features and vibration indicators in order to detect significant changes potentially associated with structural damage [3], and to support a progressive estimation of building vulnerability. The study highlights the role of data-driven and statistically informed monitoring strategies for risk mitigation in volcanic areas subjected to non-tectonic seismicity.

Keywords: Structural Health Monitoring, Bradyseismic Activity, Non-Tectonic Seismic Excitations, Vibration-Based Monitoring

References:

[1] Perelli, F.L., Di Maio, L.S., De Gregorio, D., Magliulo, G., de Martino, P., Zuccaro, G., Impact assessment caused by bradyseism phenomena in the Campi Flegrei area, Front. Built Environ. 9, 1129175 (2023).

[2] Xekalakis, G., Katzi, N.M., Apostolaki, S., Perelli, F.L., De Gregorio, D., Riga, E., Kyriakides, N., Zuccaro, G., Pitilakis, K., Christou, P., Seismic risk assessment at urban scale: comparing PLINIVS and ESRM20 methods in Cyprus, World Conf. Earthq. Eng. Proc. (2024).

[3] Das, S., Saha, P. & Patro, S.K. Vibration-based damage detection techniques used for health monitoring of structures: a review. J. Civil Struct. Health Monit. 6, 477–507 (2016)

Eigenanalysis of stress-driven nonlocal axially vibrating Bishop rods

Francesco Paolo Pinnola [a] **& Francesco Marotti de Sciarra** [a]

[a] Department of Structures for Engineering and Architecture, Università di Napoli Federico II, Naples, IT

E-mail: francescopaolo.pinnola@unina.it

Abstract

One-dimensional structural elements, such as thick nanocolumns, play a crucial role in modern engineering applications where size-dependent effects become significant. In this work, an axially vibrating stress-driven nonlocal continuum model of Bishop-type [1] is employed to investigate the modal behavior of nanocolumns, extending classical rod theory to incorporate nonlocal elastic interactions. The adopted formulation overcomes the inconsistencies associated with alternative nonlocal models while ensuring compatibility with bounded structural domains and physically consistent boundary conditions for nanoscale structural elements [2]. The classical Bishop-type local model is reformulated into a stress-driven nonlocal integral representation, in which the axial strain field is expressed as a convolution between the axial stress and a positive, symmetric, and normalized kernel function. Through this approach, an equivalent well-posed differential formulation is derived, allowing the direct determination of analytical solutions for the governing dynamic problem. The analysis is primarily focused on the modal characterization of the continuous system. In particular, closed-form expressions for the eigenfunctions are derived, enabling an analytical description of the vibration modes of the nanocolumn [3]. The influence of the nonlocal parameter on the spectral properties of the system is examined, showing that increasing nonlocal effects generally induce a stiffening-like behavior and modify the spatial distribution of the mode shapes, as well as the associated natural frequencies. The proposed framework provides an effective analytical tool for the modal analysis of axially vibrating nanoscale structural elements, offering insights into the mechanical design of nano- engineered devices such as high-frequency resonators and nanoscale structural components where size-dependent elasticity plays a dominant role.

Keywords: Bishop rod model, stress-driven nonlocality, axial vibrations, continuous eigenfunctions.

References:

[1] R.E.D. Bishop, Longitudinal Waves in Beams, Aeronautical Quarterly 3(4) (1952) 280-293.

[2] F.P. Pinnola, R. Luciano, F. Marotti de Sciarra, Bishop nanorods with stress-driven nonlocal elasticity and arbitrary boundary conditions. Mechanics Research Communications 149 (2025) 104533.

[3] F.P. Pinnola, M.S. Vaccaro, R. Barretta, F. Marotti de Sciarra, Random vibrations of stress-driven nonlocal beams with external damping, Meccanica 56(6) (2021) 1329-1344.

Generalizing Motion-Based Hybrid Strategies for Seismic Control Beyond Buildings

Diana Faiella [a], Luigi Di Sarno [a,b], Andrea Prota [a] & Elena Mele [a]

[a] Department of Structure for Engineering and Architecture, University of Naples Federico II, Naples, Italy
[b] Department of Civil and Environmental Engineering, University of Liverpool,
Liverpool, UK
E-mail: *diana.faiella@unina.it*

Abstract

Recent advancements in motion-based design have fostered hybrid response-control strategies that combine seismic isolation and mass damping by dividing a structure into dynamically interacting parts [1]. Two representative configurations are the Intermediate Isolation System (IIS), where the isolation interface is placed at an intermediate level to split the structure into a lower primary system and an upper isolated secondary system, and the Mega-Substructure Controlled System (MSCS), in which isolated substructures interact dynamically with a primary mega-frame. In both cases, relative motion activates a mass-damping mechanism associated with large mass ratios and enhanced robustness. While these concepts have been mainly developed for buildings, their potential extension to other structural typologies remains largely unexplored. Bridges often include isolation between deck and piers, yet conventional layouts do not explicitly exploit deck–pier interaction to allow the isolated deck to act as a large Tuned Mass Damper (TMD) for the piers. Industrial facilities with elevated tanks or silos, modular stacked systems, and offshore wind turbines or marine platforms similarly exhibit hierarchical layouts that can be interpreted as coupled primary–secondary systems, indicating potential for IIS- or MSCS-inspired motion-based strategies. To investigate this perspective, a unified two-degree-of-freedom model is introduced, explicitly accounting for the non-proportional damping typical of such hybrid systems. An extensive parametric study under seismic excitation is performed through response spectrum analysis by varying mass, frequency, and damping ratios over a broad range. The framework is then applied to simply-supported girder bridges with piers of varying height and slenderness. Selected optimal configurations are further examined through spectrum-compatible time-history analyses of three-dimensional numerical models. Results show that, within specific parameter regions, deck–pier interaction significantly reduces seismic demand on the piers compared to conventional bridge isolation design. These findings provide preliminary design-oriented insights toward extending motion-based hybrid control strategies across diverse structural typologies.

Keywords: motion-based design, hybrid response-control strategies, non-proportional damping, bridge dynamics

References:

[1] E. Mele, D. Faiella, Innovative mass-damping approaches for sustainable seismic design of tall buildings, in: K. Al-Kodmany, P. Du, M.M. Ali (Eds.), Sustainable high-rise buildings: design, control, and innovation, The Institution of Engineering and Technology (The IET), London, UK, 2022, pp. 345-410.

Dispersive waves in cubic lattices: a reappraisal of Goursat surfaces

Giuseppe Ruta [a], **Noël Challamel** [b], **Phu Huu Nguyen** [c] & **Chien-Min Wang** [d]

[a] Sapienza University, Rome, Italy
[b] Université Bretagne Sud, Lorient, France
[c] Van Lang University, Ho Chi Min City, Vietnam
[d] University of Queensland, St. Lucia, Australia

E-mail: giuseppe.ruta@uniroma1.it

Abstract

The justification of linear, non-linear, local, and non-local elasticity in homogeneous continuous bodies may be derived from the asymptotic limit of discrete bunches of particles interacting by standard central or non-central forces, in the wake of the path initiated by the French mechanicians Cauchy and Poisson, followed by the Italian Piola, in the early 19th century [1], and re-considered by Born, Von Kármán, Gazis, and many more, in the last century [2]. Following some previous investigations on one-and two-dimensional discrete lattices composed of geometrically regular arrangements of point-like material particles interacting by both central and non-central forces [3], in this contribution we examine three-dimensional (3D) cubic elastic lattices composed of such particles, imagined as located at the lattice vertices and spaced by an equal amount along the three characteristic directions of the cube. Each particle is assumed to interact with the neighbours up to order p (i.e., in principle we investigate interactions with molecular action extending up to a p-neighbourhood) through short- and long-range central (segmental) and non-central (angular) forces. As the inter-particle spacing (i.e. the cube edge length) tends to zero, the lattice asymptotically converges to a continuum. At the first order, i.e., for next-neighbour interactions, the lattice parameters can be calibrated to reproduce a homogeneous, linear elastic, isotropic medium with unconstrained Poisson's ratio. Higher-order asymptotic limits lead to either gradient-enhanced or non-local elastic continua. It is customary in such cases to investigate the elastic wave transmission in space and time. Here, the wave dispersion characteristics of the lattice are analysed for the simplest case of short-range interactions (p = 1, nearest-neighbour interactions only), and in a more general case (for p interactions), with particular emphasis on the role of the discrete interaction kernel. It is shown that the iso-frequency surface for each mode (transversal or longitudinal) belongs to the class of Goursat surface for the second-order asymptotic medium.

Keywords: Discrete vs. continuum elasticity; 3D lattices; Dispersion properties

References:

[1] D. Capecchi, G. Ruta, P. Trovalusci, From classical to Voigt's molecular models in elasticity. Arch. Hist. Exact Sciences 64 (2010) 525–559.

[2] N. Challamel, Y.P. Zhang, C.M. Wang, G. Ruta, F. Dell'Isola, Discrete and continuous models of linear elasticity: history and connections. Cont. Mech. Therm. 35(2) (2023) 347–391.

[3] N. Challamel, H.P. Nguyen, G. Ruta, C.M. Wang, Y.P. Zhang, Meta-Truss and Generalized Elastic Lattices with Long-Range Interactions. In: H. Altenbach, V.A. Eremeyev, (eds.), Dynamics of Discrete and Continuum Structures and Media, Advanced Structured Materials vol. 221, Springer, Cham, 2025, pp. 121-155.

MS19

Reliability-based calibration of Eurocode 3 partial safety factors for DED-Arc steel sections considering geometric and material variability

Wenxuan Hong [a], **Athina Spinasa [a]**, **Leroy Gardner [a]**

[a] Department of Civil and Environmental Engineering, Imperial College London, London, UK

E-mail: wenxuan.hong21@imperial.ac.uk

Abstract

Wire-arc directed energy deposition (DED-Arc), also known as wire arc additive manufacturing (WAAM), is an emerging manufacturing technology with significant potential to improve material efficiency, increase automation and reduce embodied carbon in the construction sector. This capability has enabled the production of large-scale steel components, prompting growing interest in their application in load-bearing structures [1]. While recent studies have examined the geometric characteristics, material properties and structural resistance of DED-Arc components, the influence of uncertainties in geometric dimensions and material properties on the reliability of existing design methods remains insufficiently understood. In particular, DED-Arc steel components exhibit greater variability in both geometric dimensions and mechanical properties than conventionally manufactured steel, challenging the assumptions embedded in EN 1993-1-1:2022 (EC3) [2]. While previous studies have statistically characterised the mechanical properties of DED-Arc steel, the variability in geometric dimensions has not yet been systematically quantified. This study addresses this gap by analysing geometric measurements reported in the literature to establish probabilistic models for key geometric parameters across different cross-sections. These geometric parameter distributions, together with previously established material property distributions, are modelled as random variables and used to calibrate partial safety factors for cross-sectional resistance under axial compression, employing both the First-Order Reliability Method (FORM) and Monte Carlo simulations in accordance with EN 1990-1:2023 (EC0) [3]. Assuming a log-normal distribution in accordance with EC0, characteristic-to-nominal yield strength ratios of 0.75 (based on nominal strengths for welding), with a typical coefficient of variation (COV) of 12%. For the geometric properties, adopting a normal distribution results in characteristic-to-nominal ratios of 0.87 and 0.97 for the thickness and outer dimensions, with typical COVs of up to 6.5% and 2.7%, respectively. Owing to this elevated variability, the calibrated partial safety factors are found to exceed those specified in EC3 for conventional structural steels. This indicates that current design provisions may underestimate the required safety margin. The findings provide a basis for the development of reliable and robust structural design rules for DED-Arc steel components.

Keywords: Reliability analysis, Partial safety factor, Statistical evaluation, Wire-arc directed energy deposition

References:

[1] L. Gardner. Metal additive manufacturing in structural engineering – review, advances, opportunities and outlook. Structures, 47:2178–2193, 2023.

[2] EN 1993-1-1:2022. Eurocode 3 – Design of steel structures – Part 1-1: General rules and rules for buildings. Standard, European Committee for Standardisation, Brussels, 2022.

[3] EN 1990-1:2023. Eurocode – Basis of structural and geotechnical design – Part 1: New structures. Standard, European Committee for Standardisation, Brussels, 2023.

A Benchmark RC Building for Uncertainty Quantification and System-Level Multi-Scale Numerical Validation of Infills and Beam-Column Joints Interaction

Marco Faggella [a], Annalisa Napoli [b], Jose Melo [a], Aslam Faqeer Mohammad [c], Omar Al Shawa [d], Roberto Realfonzo [b], Michele D'Amato [e], Domenico Liberatore [d], Humberto Varum [a], Rosario Gigliotti [d]

[a] FEUP, University of Porto, Porto, Portugal
[b] University of Salerno, Italy
[c] NED University of Engineering and Technology, Karachi, Pakistan
[d] Sapienza University of Rome, Italy
[e] University of Basilicata, Potenza, Italy

E-mail: mfaggella@gmail.com

Abstract

Existing reinforced concrete (RC) buildings designed before modern seismic provisions exhibit complex seismic vulnerabilities arising from the interaction of beam–column joints, bond-slip of smooth reinforcement, masonry infills, floor slabs, structural irregularities, and material deterioration. Although extensive experimental campaigns have been conducted on individual structural components, beam–column joints, masonry infills, strengthening techniques, and subassemblies, realistic benchmark structures representative of existing buildings remain largely unavailable.

This work brings together reviews with complementary expertise of several research groups that have contributed to the experimental characterization and numerical modeling of RC structures through component, subassembly, and frame testing, as well as the development of finite element formulations, macro-models, and performance-based assessment methodologies. Building on this collective experience, a benchmark RC building representative of this building stock is proposed as a common reference for the validation of nonlinear simulation approaches across multiple levels of structural complexity.

The benchmark is conceived as an open platform for comparing detailed finite element models, simplified macro-models, and hybrid simulation strategies, while explicitly addressing probabilistic uncertainty quantification through model-class comparison and blind prediction exercises. By integrating realistic construction details, masonry infills, floor slabs, structural irregularities, and aging-related deficiencies typical of existing buildings, the benchmark aims to bridge the gap between component-level investigations and system-level seismic assessment.

Keywords: Reinforced concrete buildings, Masonry infills, Beam-column joints, Experimental benchmark, Multi-scale numerical modeling, Uncertainty quantification, Performance-based earthquake engineering

References:

[1] Mohammad, A. F., Faggella, M., Gigliotti, R., & Spacone, E. (2023, July). Evaluation of modelling uncertainties impact in older infilled frame RC structures. In Structures (Vol. 53, pp. 764-778). Elsevier.

[2] Fernandes, C., Rodrigues, H., & Varum, H. (2014). Cyclic behaviour of interior beam–column joints reinforced with plain bars. Earthquakes and Structures, 7(6), 1151-1167.

[3] Grande, E., Imbimbo, M., Napoli, A., Nitiffi, R., & Realfonzo, R. (2021). A Nonlinear Macro-Model for the Analysis of Monotonic and Cyclic Behaviour of Exterior RC Beam-Column Joints. Frontiers in Materials, 8, Article 719716.

Unsteady Flow Numerical Study of Local Scour around Pile Groups

Jian Guo [a,b], Chenyu Hu [a,b], Tong Wang [a,b]

[a] State Key Laboratory of Bridge Intelligent and Green Construction, Southwest Jiaotong University, Chengdu Sichuan, China

[b] School of Civil Engineering, Southwest Jiaotong University, Chengdu, China

E-mail: *guoj@vip.163.com*

Abstract

With extreme climate events become more frequent, local scour around pile group foundations has become a critical factor in structural safety deterioration, and even bridge collapse. Steady flow research has left tandem pile scour under unsteady flood loads unclear and needing further investigation. In this study, a comprehensive three- dimensional coupled hydrodynamic-structure-riverbed model was developed using the computational fluid dynamics software Flow-3D. To realistically capture the temporal uncertainty of flood hydrographs, the rising phase of the flood wave was discretized into six equal time intervals, enabling detailed simulation of the local scour process around tandem pile groups under unsteady flow conditions. The numerical results indicate that scour development is largely completed during the rising phase. For the front pile, the maximum scour depth occurs immediately upstream, reaching 0.145 m. For the rear pile, the scour depths at the side and behind the pile are 0.017 m and 0.145 m, respectively. Notably, in contrast to steady flow conditions, minimal deposition is observed in the wake region behind the pile group under unsteady flow. Furthermore, the simulated scour depth reaches 93% of the maximum scour depth predicted under steady flow conditions within a relatively short period, underscoring the need for real-time scour monitoring and early warning systems during the flood rising phase to support effective structural risk assessment under uncertain disaster loads.

Keywords: unsteady flow; local scour; group piles

References:

[1] B. W. Melville., Local Scour at Bridge Sites. University of Auckland, School of Engineering, Auckland, New Zealand, 1975.

[2] B. Sumer., R. Whitehouse., and A. Torum. Scour around coastal structures: A summary of recent research, Coastal Engineering. 2001, 44(2), 153-190.

[3] W. Zhang., R. Nie., X. Liu., et al. Clear-water scour depth at rock weirs under unsteady flows, Journal of Hydrology. 2025, 654, 132889.

[4] J. Lai., W. Y. Chang., and C. L. Yen. Maximum Local Scour Depth at Bridge Piers under Unsteady Flow, Journal of Hydraulic Engineering. 2009, 135(7), 609-614.

[5] S. Y. Kumcu. Steady and unsteady pressure scour under bridges at clear-water conditions, Canadian Journal of Civil Engineering. 2016, 43(4), 334-342.

MS20

Hyper-reduced order modeling of inelastic arbitrary Lagrangian Eulerian simulations for a digital twin of the road

Jannick Kehls [a], **Stephan Ritzert** [a], **Stefanie Reese** [a,b] **& Tim Brepols** [a]

[a] Institute of Applied Mechanics, RWTH Aachen University, Germany
[b] University of Siegen, Germany

E-mail: *jannick.kehls@ifam.rwth-aachen.de*

Abstract

Digital twins of road systems require high-fidelity finite element method (FEM) simulations that can be executed fast enough to support prediction, monitoring, and decision-making under evolving loading and environmental conditions. Achieving this performance is particularly challenging for inelastic material models, where history-dependent state variables must accurately evolve at the material-point level. Therefore, a multi-layer reduction strategy for fast FEM simulations tailored to digital twins of road infrastructures is presented. First, an Arbitrary Lagrangian–Eulerian (ALE) formulation is employed to confine the computational domain to a moving region of interest, significantly reducing the number of active degrees of freedom while retaining full spatial resolution in critical zones [1]. Building on this reduced mesh, a hyper-reduced order model based on energy-conserving sampling and weighting [2] is created to further accelerate the computations, leading to the final hyper-reduced domain that is evaluated during the FEM simulation. A key challenge addressed in this work is the treatment of inelastic materials under ALE kinematics, where advection of material points leads to a non-trivial evolution of history variables. To this end, we reconstruct the material history using a gappy proper orthogonal decomposition [3] framework, enabling accurate recovery of internal variables on the whole domain based on the material point information of the hyper-reduced domain. Numerical examples relevant to road systems demonstrate substantial speed-ups compared to full-order simulations, while maintaining accuracy in both global responses and local inelastic behavior. The proposed approach provides an efficient and robust building block for real-time-capable digital twins of road systems, bridging the gap between high-fidelity inelastic FEM and operational performance requirements.

Keywords: model order reduction, hyper-reduction, digital twin, arbitrary lagragian eulerian

References:

[1] Anantheswar, A., Kehls, J., Wollny, I., Brepols, T., Reese, S., & Kaliske, M., Development of a Model Order Reduced Arbitrary Lagrangian Eulerian (MORALE) formulation for structures subjected to dynamic moving loads. International Journal for Numerical Methods in Engineering (2025) 126(24): e70229.

[2] Farhat, C., Avery, P., Chapman, T., & Cortial, J., Dimensional reduction of nonlinear finite element dynamic models with finite rotations and energy-based mesh sampling and weighting for computational efficiency. International Journal for Numerical Methods in Engineering (2014) 98(9): 625-662.

[3] Everson, R., & Sirovich, L., Karhunen–Loeve procedure for gappy data. Journal of the Optical Society of America A (1995) 12(8): 1657-1664.

AData-drivenmultiscale Lattice Discrete Particle Model(LDPM) for digital twin modeling of concrete structures

Baixi Chen[1], Alessandro Fascetti[1]

[1] Department of Civil, Environmental and Construction Engineering, University of Central Florida, Orlando FL, 32816 USA

Abstract

Degradation, damage, and failure mechanics in cementitious composites exhibit significant variability at the macroscopic scale, which is predominantly driven by stochasticity at the spatial scale of the coarse aggregate particles, referred to in this context as mesoscopic scale. However, mesoscale material parameters are difficult to estimate, making uncertainty quantification a fundamental scientific and engineering challenge. To address this limitation, a data-driven multiscale inverse inference framework is proposed to quantify the stochastic mesoscale behavior by integrating both mesoscale and macroscale observations. In this framework, a stochastic data-driven model using a hybrid Proper Orthogonal Decomposition–Gaussian Process Regression (POD-GPR) algorithm is first developed based on data generated by mesoscale Lattice Discrete Particle Model (LDPM) simulations. Leveraging this efficient data-driven model, a novel multiscale Bayesian inverse inference method is proposed to infer the stochastic distributions of the mesoscale features. When applied to experimental data, the proposed framework successfully captures the stochastic distributions of mesoscale material parameters, reproduces macroscale responses, and outperforms conventional single-scale Bayesian inference approaches. Additionally, SHapley Additive exPlanations (SHAP) are integrated to further interpret the effect of mesoscale stochastic material behavior on macroscale uncertainty, offering valuable insights for the accuracy improvement of LDPM simulations and future mesoscale-level optimization to achieve more robust macroscale performance.

Domain-Guided Probabilistic Graphical Model for Structurally Context-Aware Component Classification

Rodrigo Sarlo[a], **Yunus Kantekin**[a]

[a] Civil & Environmental Engineering, Virginia Tech, Blacksburg, VA, USA

E-mail: sarlo@vt.edu

Abstract

Automated structural model generation from sensor and inspection data requires not only identification of individual structural components, but a contextual understanding of how those components relate to one another. Existing structural engineering approaches have made progress in component labeling yet largely overlook spatial and functional dependencies among components—a critical gap for producing valid analytical models. This work proposes an ontology-guided Probabilistic Graphical Model (PGM), specifically a Conditional Random Field (CRF), trained on a synthetically generated dataset of labeled structural components to perform structurally context-aware classification. The framework is built around two core elements. First, a structural engineering ontology is developed using Web Ontology Language (OWL), defining hierarchical concepts—such as members, beams, columns, and connections—along with their interrelations. The ontology establishes the graph structure on which the CRF operates and drives a multi-stage labeling strategy that progresses from general component categories to specialized subtypes and finally to connections, limiting the label space at each stage to improve classification performance. Second, a large synthetic training dataset is generated programmatically using a combination commercial structural design software (Tekla Structures) and a custom LiDAR Data Synthesizer. Point-level component labels—including beams, columns, slabs, connections—are extracted to simulate the noisy output of a segmentation algorithm, which would be prohibitively difficult to obtain at scale from real-world data collection. The CRF is formulated with unary potential functions capturing individual component properties (cross sections, orientation, etc.) and pairwise potential functions encoding spatial and co-occurrence dependencies between component pairs. Model weights are trained simultaneously on the synthetic dataset. The resulting labeled graph encodes member types, cross-sections, boundary conditions, and connection types, providing the structural information necessary for analytical model generation. Framework performance is evaluated using graph similarity scores against reference synthetic models, with a target average similarity of 75%.

Keywords: probabilistic graphical model, conditional random field, structural component classification, synthetic dataset, structural ontology

MS21

Efficiency Assessment of Urban Road Networks Connecting Critical Nodes under Seismic Hazard

Andrea Miano [a], **Marco Civera** [b], **Valerio De Biagi** [b], **& Fulvio Parisi** [c]

[a] Department of Engineering, Telematic University Pegaso, Centro Direzionale Isola F2, 80143 Napoli, Italy
[b] Department of Structural, Building and Geotechnical Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Turin, Italy
[c] Department of Structures for Engineering and Architecture, University of Naples "Federico II", Via Claudio 21, 80125 Naples, Italy

E-mail: *andrea.miano@unipegaso.it*

Abstract

The resilience of urban road networks is a key component of sustainable infrastructure systems, particularly in seismic-prone regions where network functionality is critical for emergency response. This study proposes a multidisciplinary framework for assessing the post-earthquake efficiency of urban road networks. The proposed method [1] explicitly accounts for the interaction between transportation infrastructure and the surrounding built environment, and the network efficiency is defined as the travel time between critical node pairs, such as hospital-to-hospital connections, and is evaluated under probabilistic seismic scenarios.

The methodology integrates GIS-based road network modelling with seismic hazard analysis and vulnerability assessment of bridges [2] and adjacent buildings [3]; that is to say, seismic-induced damage is simulated using Monte Carlo analyses, enabling the identification of road disruptions caused by both direct infrastructure damage and building collapses that obstruct roadways. An efficiency index based on travel time is used to quantify network performance before and after seismic events.

The proposed framework is applied to two representative Italian case studies, one in Naples and the other in Turin, characterized by different urban layouts, infrastructure typologies, and seismic hazard levels. Results highlight significant variability in network efficiency degradation, depending on seismic intensity, infrastructure configuration, and availability of alternative routes. In some scenarios, moderate seismic events are shown to cause substantial efficiency losses due to widespread minor damage affecting multiple network components.

Keywords: road networks; seismic resilience; network efficiency; critical infrastructure

References:

[1] Miano, A., Civera, M., Aloschi, F., De Biagi, V., Chiaia, B., Parisi, F., & Prota, A. (2024). Efficiency assessment of urban road networks connecting critical node pairs under seismic hazard. Sustainability, 16(17), 7465.

[2] Moschonas, I. F., Kappos, A. J., Panetsos, P., Papadopoulos, V., Makarios, T., & Thanopoulos, P. (2009). Seismic fragility curves for Greek bridges: methodology and case studies. Bulletin of Earthquake Engineering, 7(2), 439-468.

[3] Rosti, A., Del Gaudio, C., Rota, M., Ricci, P., Di Ludovico, M., Penna, A., & Verderame, G. M. (2021). Empirical fragility curves for Italian residential RC buildings. Bulletin of Earthquake Engineering, 19(8), 3165-3183.

A Probabilistic Framework for Multi-Hazard Bridge Assessment with Operational Downtime Estimation

Enrico Cianci [a], **Marco Civera** [a], **Valerio De Biagi** [a], **Bernardino Chiaia** [a]

[a] Department of Structural, Building and Geotechnical Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Turin, Italy

E-mail: *enrico.cianci@polito.it*

Abstract

Bridges are increasingly exposed to interacting natural hazards whose combined effects may significantly influence structural performance and operational continuity. While fragility-based assessment procedures are well established for single hazards [1], the interaction between sequential or concurrent events may substantially modify failure probabilities and performance estimates [2]. Moreover, quantifying post-event functionality and downtime remains a key aspect of infrastructure resilience evaluation [3]. This contribution presents a probabilistic framework for explicitly accounting for hazard interactions in bridge risk assessment, with specific attention to the estimation of operational closure time. Hazard sequences and conditional failure-propagation mechanisms are represented using event-tree structures, enabling the systematic description of cascading and interacting scenarios. Bayesian updating strategies are considered to incorporate inspection or monitoring information into the probabilistic model as new information becomes available. Uncertainty propagation from hazard intensity measures to structural demand and damage states is evaluated through Monte Carlo simulation, supporting the derivation of fragility relationships consistent with performance-based engineering principles and extended to interacting loading conditions. The framework links structural damage states to operational consequences, allowing the estimation of potential downtime and traffic interruption following damaging events. The proposed framework is formulated for bridge systems exposed to multiple interacting hazards, including seismic and climate-related events. It provides a consistent probabilistic framework for capturing interaction effects and estimating functional recovery times, thereby supporting risk-informed bridge management and decision-making.

Keywords: Multi-hazard risk assessment; Hazard interaction modelling; Bridge risk analysis; Functional recovery time

References:

[1] I.F. Moschonas, A.J. Kappos, P. Panetsos, V. Papadopoulos, T. Makarios, P. Thanopoulos, Seismic Fragility Curves for Greek Bridges: Methodology and Case Studies, Bull. Earthq. Eng. 7 (2009) 439–468.

[2] F. Kameshwar, J.E. Padgett, Multi-Hazard Risk Assessment of Highway Bridges Subjected to Seismic and Hurricane Hazards, Eng. Struct. 78 (2014) 154–166.

[3] M. Bruneau, S.E. Chang, R.T. Eguchi, G.C. Lee, T.D. O'Rourke, A.M. Reinhorn, M. Shinozuka, K. Tierney, W.A. Wallace, D. von Winterfeldt, A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities, Earthq. Spectra 19 (2003) 733–752.

Bayesian Diagnostic Reliability of Dual-Source Dam-Springs Water Infrastructure under Non-Stationary Climate and Regulatory Constraints

Marco Faggella [a], Giampiero D'Ecclesiis [b] & Andre R. Barbosa [c]

[a] Affiliate Researcher (CONSTRUCT FEUP, University of Porto, Porto, Portugal)
[b] Geologist (Potenza, Italy)
[c] Professor (Oregon State University, Corvallis, Oregon, US)

E-mail: *mfaggella@gmail.com*

Abstract

Traditional reliability assessments of dual-source systems—comprising surface reservoirs and groundwater springs—assume component independence. Historically, karst springs provided a high-inertia, lagged supply that buffered seasonal reservoir depletion. This paper presents a framework to quantify how climate non-stationarity synchronizes these previously distinct hydrological processes, inducing a latent Common Cause Failure (CCF) mode. Temperature induced early snowmelt bypasses subsurface infiltration, simultaneously depleting spring yields and generating a surface runoff pulse that coincides with reservoir peak levels. This synchronization can be compounded by rigid safety-driven storage limits (NTC18 seismic and NTD14 flood regulations), which mandate the discharge of this synchronized pulse, preventing the reservoir from buffering the lost spring supply. The framework utilizes a Total Probability partition to model the transition from independent to coupled states. A Bayesian diagnostic is developed to update reliability in real-time: an early-season spill is identified as a mathematical precursor to summer supply failure. Results indicate that under non-stationary coupling, system risk "flips" from a marginal product of independent probabilities to a dominant, single-point hazard. This approach provides a mechanics-based foundation for adaptive infrastructure management where regulatory safety margins inadvertently amplify systemic drought vulnerability.

Keywords: non-stationary hydrology, Bayesian reliability, dam-karst springs systems, regulatory drought risk

References:

[1] M. Faggella, M., A.R. Barbosa, Camastra Dam Failure: Earthquake Collapse versus Total Reservoir Loss Risk Aversion, ASCE OPEN: Multidisciplinary Journal of Civil Engineering, 3(1) (2025) 04025008.

[2] G. D'Ecclesiis, M.Polemio, Condizioni di emergenza di alcune tra le principali scaturigini della Basilicata, Geologica Romana, 30 (1994) 105-112.

[3] S. Ortenzi, L. Di Matteo, D. Valigi, M. Donnini, M. Dionigi, D. Fronzi, J. Geris, F. Guadagnano, I. Marchesini, P. Filippucci, F. Avanzi, D. Penna, C. Massari, Exploring groundwater-surface water interactions and recharge in fractured mountain systems: an integrated approach. EGUsphere, (2025), 1-37.

Optimizing Resilience of Ground-Mounted PV Support Structures under Extreme Flood Hazards

Wenzhu Li [a], **Ashraf Osman** [a], **Hailiang Du** [b], **Mahmoud Shahbazi** [a], **Peter Matthews** [a], **Hongjian Sun** [a]

[a] Department of Engineering, Durham University, Durham, United Kingdom
[b] Department of Mathematical Sciences, Durham University, Durham, United Kingdom
E-mail: wenzhu.li@durham.ac.uk

Abstract

Ground-mounted photovoltaic (PV) plants are frequently installed on low-relief sites with high flood exposure [1], where the steel support frames and their foundations constitute the critical load-bearing components. However, current design checks are largely deterministic and do not explicitly quantify structural resilience under hydraulic uncertainty [2], leading to potential underestimation of serviceability demand. To address this gap, this study develops a performance-based probabilistic framework in three coupled stages: (i) RANS-based CFD simulations (VOF free-surface model, standard k–ε closure) to derive hydrodynamic pressure distributions; (ii) finite-element analysis of single-frame and four-row array configurations to compute member stresses and lateral displacements; and (iii) stochastic characterization of flood depth and velocity to construct fragility and risk curves [3]. Results show that member stresses remain below yield limits in all scenarios. Under severe flooding, lateral displacement exceeds the serviceability threshold of $L/250$ (JG/T 490-2016), confirming a deformation-controlled failure mode. Peak displacement increases approximately linearly with flow velocity but shows a non-monotonic dependence on flood depth, peaking near 2.0 m, owing to competing effects of increasing hydrodynamic force and flow separation at greater submergence. At the array scale, increasing flood intensity shifts peak displacement progressively downstream, reflecting significant row-to-row hydrodynamic interaction. For probabilistic assessment, flood depth and velocity are treated as independent Weibull-distributed variables. A critical flood depth of 1.82 m is identified, beyond which failure probability exceeds 90%. Risk curve analysis recommends a design return period of 20 years. Overall, the framework replaces deterministic design checks with mechanics-informed, probability-based performance criteria, offering a practical tool for flood resilience optimization of ground-mounted PV installations and other lightweight structures with deformation-controlled failure modes.

Keywords: flood resilience, fluid–structure interaction, PV support structures, performance-based design, probabilistic mechanics.

References:

[1] P.C. Okonkwo, S.C. Nwokolo, S.O. Udo, et al., Solar PV Systems Under Weather Extremes: Case Studies, Classification, Vulnerability Assessment, and Adaptation Pathways, Energy Reports 13 (2025) 929–959.

[2] K. Yılmaz, A.E. Dinçer, and E.N. Ayhan, Exploring Flood and Erosion Risk Indices for Optimal Solar PV Site Selection and Assessing the Influence of Topographic Resolution, Renewable Energy 216 (2023) 119056

[3] W. Li, L.S. Cunningham, et al., Structural Resilience of Pole-Mounted Substations Subjected to Flooding: Generalized Framework and a Malaysian Case Study, ASCE-ASME J. Risk Uncertainty Eng. Syst., Part A: Civ. Eng. 10(2) (2024) 04024008.

MS22

Visualization of Disaster Mechanisms in Tunnel Structures Crossing Faults

Longjun Xu [a], Heng Zhang [b] & Jie Wang [a]

[a] Institute of Explosion and Blasting Technology, Jianghan University, Wuhan, China
[b] Institute of Engineering Mechanics, China Earthquake Administration, Harbin, China

E-mail: *67283321@qq.com*

Abstract

This study aims to reveal the critical link between the dislocation resistance of cross-fault tunnels and the fault propagation process in the surrounding rock. To this end, a refined numerical modeling method based on the cohesive zone model (CZM) was developed. This method does not require predefined crack paths and can simulate rock fracture and its coupled response with tunnel structures, while also establishing a standardized process for determining the CZM parameters of the surrounding rock. After validation through three types of experiments, the model demonstrated significant advantages over traditional finite element methods in capturing fracture evolution, tunnel deformation, and failure mechanisms. Parametric studies revealed that key CZM parameters—maximum allowable stress, interface stiffness, and fracture energy—synergistically influence rock fracture and structural dislocation. Additionally, wider fault zones promote energy dissipation and distributed cracking, shorter tunnel segments enhance deformation adaptability, and lower fault dip angles tend to intensify oblique rupture damage. These findings provide important mechanistic insights and parameter-based guidance for the anti-dislocation design of cross-fault tunnels.

Keywords: Cross-fault tunnels, Fracture simulation, Cohesive elements, Element failure

References:

[1] Alfano, G., 2006. On the inffuence of the shape of the interface law on the application of cohesive-zone models. Compos. Sci. Technol. 66 (6), 723–730.

[2] Baziar, M.H., Nabizadeh, A., Jung Lee, C., Yi Hung, W., 2014. Centrifuge modeling of interaction between reverse faulting and tunnel. Soil Dyn. Earthq. Eng. 65, 151–164.

[3] Ba, Z., Wang, Y., Li, D., 2025. Numerical investigation on seismic damage of tunnels subjected to fault dislocation using the FDM-DEM approach. Comput. Geotech. 182, 107169.

A visualized computational framework for irregular granular geomaterials combining generative modeling, neural shape representation, and multiscale CFD- DEM simulation

Chenghao Li [a,b], Zhengshou Lai [a,b], Shuai Huang [a], Linchong Huang [a,b]

[a] State Key Laboratory of Tunnel Engineering, Sun Yat-sen University, Zhuhai, China
[b] School of Civil Engineering, Sun Yat-sen University, Zhuhai, China

E-mail: hlinch@mail.sysu.edu.cn

Abstract

Realistic particle morphology and internal pore structure play crucial roles in governing the hydro-mechanical behavior of granular geomaterials, yet their unified treatment in geotechnical computation remains challenging. This study presents a visualized computational framework for irregular granular geomaterials by integrating generative modeling, neural implicit shape representation, and multiscale fluid-particle simulation. First, a diffusion-based generative framework is employed to create virtual porous granular media with realistic morphological diversity, providing an efficient way to generate representative particle samples beyond conventional reconstruction-based approaches. Second, a neural-network-driven signed distance field method is adopted for high-fidelity representation of irregular particle geometries, enabling accurate shape reconstruction, geometric queries, and computational particle mechanics within a unified implicit formulation. Third, these developments are incorporated into a hybrid resolved-unresolved CFD-DEM framework for multiscale fluid-particle systems involving irregular-shaped and polydisperse particles, achieving a balance between physical fidelity and computational efficiency. To demonstrate the engineering relevance of the proposed framework, it is further applied to the analysis of suffusion behavior in coral sand, with particular attention to the effects of irregular particle morphology and intraparticle voids on seepage-induced particle migration, hydraulic response, and microstructural evolution. The results show that data-driven particle generation, neural implicit geometry, and multiscale coupled simulation can be effectively linked into a coherent workflow for visualized geotechnical computational mechanics.

Keywords: Irregular granular geomaterials; Neural signed distance field; Diffusion-based generation; Multiscale CFD-DEM

References:

[1] Li, C., Lai, Z., Huang, S., & Huang, L. (2026). Neural network-driven shape representation and computational particle mechanics via signed distance fields. Engineering Applications of Artificial Intelligence, 167, 113913.

[2] Lai, Z., Huang, S., Kong, Y., Zhao, S., Zhao, J., & Huang, L. (2026). Hybrid resolved-unresolved CFD-DEM framework for multiscale fluid-particle systems with irregular-shaped and polydisperse particles. Journal of Computational Physics, 114759.

[3] Huang, S., Wang, P., Lai, Z., Yin, Z. Y., Huang, L., & Xu, C. (2026). Hybrid SDF-CFD-DEM analysis of suffusion behavior in coral sand incorporating irregular particle morphology and intraparticle voids. Engineering Geology, 364, 108616.

Investigating the Dynamic Behavior of Metaconcrete with Stabilized Soil Aggregates

Giuseppina Di Chiara [a,b], **Marco Miniaci** [c], **Ilenia Farina** [d], **Antonella Petrillo** [d], **Raimondo Luciano** [d], **Fernando Fraternali** [a]

[a] Department of Civil Engineering, University of Salerno, Fisciano, Italy
[b] Department of Civil Engineering and Architecture, University of Catania, Catania, Italy
[c] Dipartimento di Ingegneria Strutturale, Edile e Geotecnica, Politecnico di Torino, Torino, Italy
[d] Department of Engineering, University of Naples "Parthenope", Napoli, Italy

Abstract

Metaconcrete has recently emerged as a highly promising concept in the field of metamaterials; it is an engineered medium exhibiting unconventional wave-guiding capabilities. Typically, this material is obtained by replacing conventional gravel with engineered aggregates embedded within a cementitious mortar [1]. In our study, conventional aggregates are replaced with bi- material inclusions, designed with a specific focus on the sustainable reuse of contaminated soils previously treated through a solidification/stabilization (S/S) process [2]. The S/S procedure transforms polluted soils into stable and non-reactive materials, drastically reducing environmental risks. The proposed material integrates soil remediation strategies with the design of functional cement- based metamaterials, providing a sustainable solution for the mitigation of vibrations and stress waves [3], as demonstrated by several recent studies [4-5]. Through an experimental campaign involving the casting of cylindrical specimens, the stabilized soil was mechanically characterized by determining its Young's modulus and Poisson's ratio. Using these properties, analytical models and finite element method (FEM) simulations were developed to predict the dynamic behavior of the metaconcrete. By applying the Bloch-Floquet theory to a representative unit cell, dispersion analyses were performed to map the bandgaps associated with local resonance phenomena. The results highlight a distinct longitudinal bandgap between 6.5 and 7.5 kHz, confirming the validity of the multiscale model through an excellent agreement between the analytical data and the numerical simulations. Numerically, it emerges that local resonance traps energy within the compliant coating, significantly attenuating longitudinal wave propagation. Overall, the research demonstrates that utilizing stabilized and encapsulated contaminated soils as resonant inclusions in metaconcrete is an effective solution that marries environmental sustainability with advanced damping capabilities. The proposed formulation offers excellent application prospects for acoustic insulation, seismic shielding, vibration mitigation, and blast-resistant structural systems.

Keywords: Metaconcrete, Soil remediation, Wave Mitigation, Mechanical characterization

References:

[1] Mitchell, S.J., A. Pandolfi, and M. Ortiz, Metaconcrete: designed aggregates to enhance dynamic performance. Journal of the Mechanics and Physics of Solids, 2014. 65: p. 69-81.

[2] Petrillo, A., Fraternali, F., Acampora, A., Di Chiara, G., Colangelo, F., & Farina, I., Innovative Solidification and Stabilization Techniques Using Industrial By-Products for Soil Remediation, Applied Sciences,2025, 15(7), 4002.

[3] Milton, G.W. and J.R. Willis, On modifications of Newton's second law and linear continuum elastodynamics. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2007. 463(2079): p. 855-880.

[4] Briccola, D., M. Ortiz, and A. Pandolfi, Experimental Validation of Metaconcrete Blast Mitigation Properties. Journal of Applied Mechanics, 2017. 84(3): p. 031001.

[5] Kettenbeil, C. and G. Ravichandran, Experimental investigation of the dynamic behavior of metaconcrete. International Journal of Impact Engineering, 2018. 111: p. 199-207.

Homogenization Techniques for Granular Materials: A Critical Review

Aditya Roy Chowdhury [a], Mousumi Mukherjee [b] & Arindam Dey [a]

[a] Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati, India
[b] School of Civil and Environmental Engineering, Indian Institute of Technology Mandi, Mandi, India

E-mail: mousumi@iitmandi.ac.in; mousumi.ju06@gmail.com

Abstract

Granular materials are ubiquitous in nature and are usually composed of millions of discrete particles. While numerically solving engineering scale problems with such particulate materials, either following a discrete or continuum approach, it becomes imperative to adopt a homogenization strategy to aid the computational efficiency. Homogenization techniques ensure that the underlying discreteness of the granular assembly does not introduce errors in the calculations of representative field variables of the ensemble, which is often characterized by a chosen representative volume element (RVE) at meso-level. Some of the available techniques for such homogenization are discussed in this review. This includes traditional volume averaging methods, where the stress tensor can be related to the outward-oriented contact forces of an RVE while the strain tensor is related to the displacements of the boundary particles of the RVE [1]. On the contrary, some of the authors have employed energy postulates to link the micro-macro field variables, and derived different frameworks for identifying compatible stress-strain fields at the meso-scale [2]. However, challenges remain in determination of the RVE size for such volume averaging. Additionally, differential expansions and integral transformations have also been applied to derive the meso-level field variables leading to Cosserat continuum and non-local Cosserat continuum descriptions, respectively [3]. Such theories have been well applied for different applications starting from studying mechanical behavior to mixing problems and thermal effects in granular media.

Keywords: Granular materials, homogenization techniques, RVE, micro-meso-macro (MMM)

References:

[1] C. Wellmann, C. Lillie, P. Wriggers, Homogenization of granular material modeled by a three-dimensional discrete element method, Comput Geotech. 35 (2008) 394–405.

[2] P.Y. Hicher and C.S. Chang, Evaluation of Two Homogenization Techniques for Modeling the Elastic Behavior of Granular Materials, J. Eng. Mech. 131(11) (2005) 1184-1194.

[3] E. Pasternak and H.B. Mühlhaus, Generalised homogenisation procedures for granular materials, In: Hill, J.M., Selvadurai, A. (eds) Mathematics and Mechanics of Granular Materials. Springer, Dordrecht. https://doi.org/10.1007/1-4020-4183-7_12.

EMI ASCE

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

DiSt Department of Structures for Engineering and Architecture

DiSt 2023-2027 DIPARTIMENTO DI ECCELLENZA MUR

EMI 2026 IC

ASCE Engineering Mechanics Institute 2026 International Conference

September 2 - 4, 2026

Napoli, Italy