Engineering Mechanics Institute International Conference 2018

2 – 4 November, 2018
Tongji University, Shanghai, China

Sponsored by

Tongji University
National Natural Science Foundation of China
The Chinese Society of Theoretical and Applied Mechanics
Architectural Society of China
Shanghai Society of Theoretical and Applied Mechanics
Chinese Society for Vibration Engineering

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WELCOME FROM THE EMI PRESIDENT

Professor George Deodatis

Columbia University, New York City

Dear Participants of the 2018 EMI International Conference,

As I start my second year of service as President of EMI, I would like to express my sincere thanks to the extraordinary dedication, commitment and hard work of the Board of Governors, the EMI staff, the technical committees, and our members in the U.S. and around the globe. On behalf of EMI, I would like to thank Prof. Jie Li (Tongji University), Conference Chair, Prof. Jianbing Chen (Tongji University), Prof. Xiaodan Ren (Tongji University), and Prof. Jian-Ying Wu (South-China University of Technology), Co-Chairs of the Local Organizing Committee, for organizing and hosting this year's EMI International Conference. I would also like to thank all the members of the Local Organizing Committee and all the members of the International Scientific Committee for their valuable contributions to the success of the conference.

The ever-increasing attendance at the EMI conferences reflects EMl's growing reputation as the premier venue for engineering mechanics. In addition to the vibrant technical programs offered over the past ten years at EMI conferences, our Institute has experienced a healthy increase in its membership and has greatly benefited from the stellar reputation of our flagship publication, the ASCE Journal of Engineering Mechanics, under the inspiring editorship of Prof. Roberto Ballarini (University of Houston).

I invite you to get more involved with our institute. EMI will further grow and thrive only if the requisite hard work is shared among its members. Opportunities for engagement include publication in the ASCE Journal of Engineering Mechanics and the Lecture Notes in Mechanics Series, active participation on technical committees, organization of conference sessions and symposia, engagement in the EMI industry collaboration, delivery of webinars, and seeking leadership roles on committees and the Board of Governors.

I wish you an enjoyable and productive conference.

Yours truly,

Deodatis Georgios

Background and Aim

Created on October 1, 2007, the Engineering Mechanics Institute (EMI) replaces the former ASCE Engineering Mechanics Division. EMI has two annual conferences, one in the United States and another internationally. These conferences offer a place to exchange ideas, present your work, and see what others are doing. The fundamental advances in engineering mechanics are here on display. These conferences present premier opportunities to network with leaders in the field, expand your horizons, and establish professional relationships to advance your research and your career. EMI conferences also showcase some of the brightest students who participate in student competitions.

The 2018 EMI International Conference will be held at Tongji University, Shanghai, China during Nov. 2-4th, 2018. This event will be a forum to present the newest findings and to depict the future development in Engineering Mechanics as the core discipline of science-enabled Civil Engineering understood in the broadest sense.

Conference Co-Chairs

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George Deodatis, Columbia University

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Amar Chaker, ASCE/EMI

Verna Jameson, ASCE/EMI

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Lu Hai	Tongji University		

Poster Session

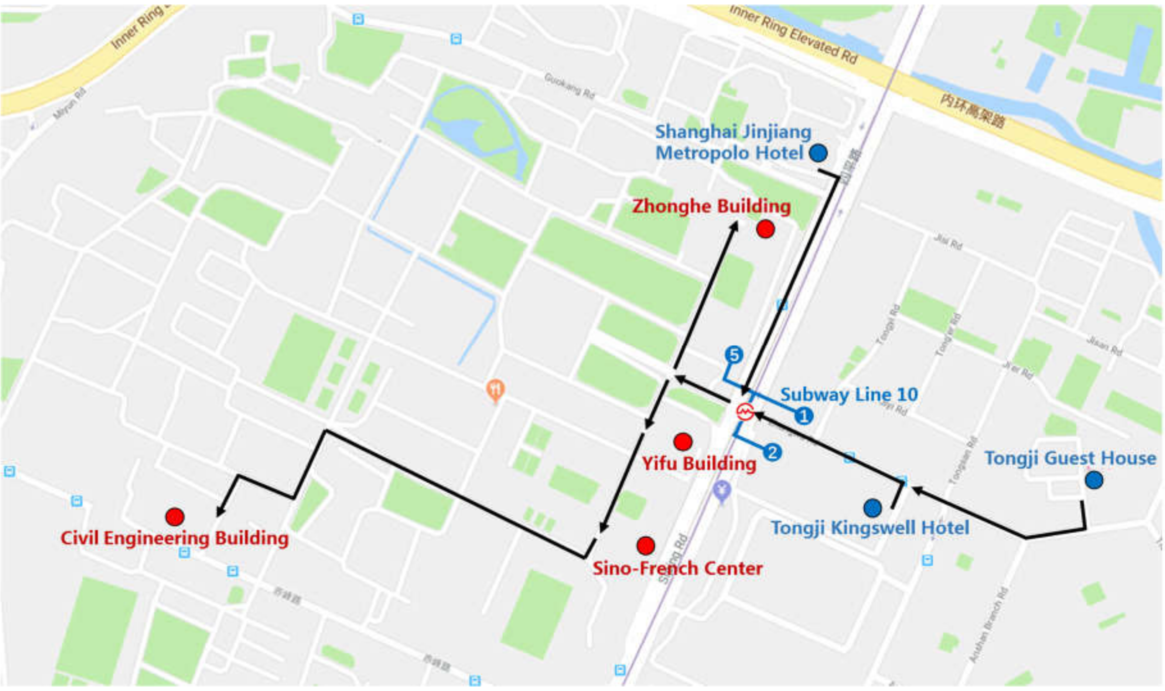
Poster Session will be held at the B-floor of the Sino-French Center of Tongji University during the conference. Presenters should put up your posters on the morning of November 3th.

Conference Venue

Conference venue: Tongji University

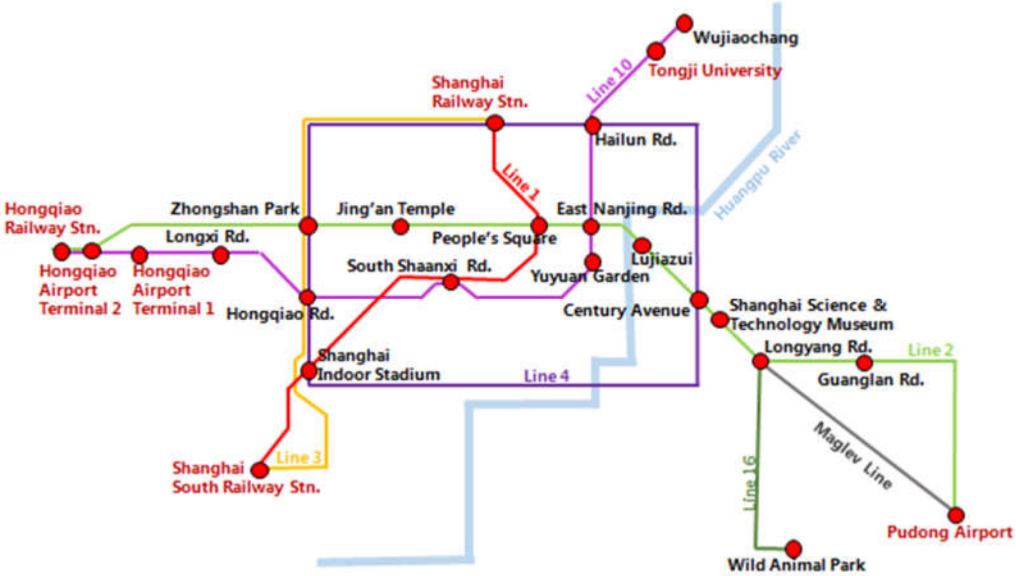
Address: 1239 Siping Road, Shanghai, China

Map of Venue



Sino-French Center

Transportation



（1）From Pudong International Airport (PVG)

☞by Metro Line 2 to "**East Nanjing Road**" and transfer Metro Line 10 to "**Tongji University**" stop (about 100 minutes / RMB 7.00)

☞by Taxi (about 60 minutes / RMB 160.00)

（2）From Hongqiao International Airport (SHA) or Hongqiao Railway Station

☞by Metro Line 10 to the "**Tongji University**" stop (about 60 minutes / RMB 5.00)

☞by Taxi (about 50 minutes / RMB 110.00)

（3）From Shanghai Railway Station

☞by Metro Line 4 to "**Hailun Road**" and transfer Metro Line 10 to "**Tongji University**" stop (about 40 minutes / RMB 4.00)

☞by Taxi (about 30 minutes / RMB 40.00)

（4）From Shanghai South Railway Station

☞by Metro Line 3 to "**Hongqiao Road**" and transfer Metro Line 10 to "**Tongji University**" stop (about 70 minutes / RMB 5.00)

☞by Taxi (50 minutes / RMB 90.00)

Contacts

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Program

Program: Day 2-Friday, 2 Nov 2018

Time	Venue
14:00—21:30	Registration
	The 3rd floor of Kingswell Hotel VIP Room
19:00—21:00	Ice Breaker Reception
	The 3rd floor of Kingswell Hotel Ball Room

Program: Day 3-Saturday, 3 Nov 2018

Time	Venue					
8:00—18:00	Registration(Sino-French Center Room C201)					
8:30—8:50	Welcoming Remarks					
8:50—9:00	Group Photo					
	Plenary Lectures Chair(s): Prof. Pol D. Spanos					
9:00--9:40	Design of New Materials and Structures to Maximize Strength at Probability Tail: A Neglected Challenge for Quasibrittle and Biomimetic Materials Prof. Zdeněk P. Bažant - Northwestern University, USA					
9:40--10:20	Engineering Dynamics of Soft Machines Prof. Hai-Yan Hu - Beijing Institute of Technology, P.R. China					
10:20--10:40	Coffee Break (The 1st floor of Sino-French Center)					
	Sino-French Center Room C201	Sino-French Center Room C401	Yifu Building Room 113	Sino-French Center Room A401	Tongji University Zhonghe Building Room 1002	Tongji University Zhonghe Building Room 802
Session	MS3: Instabilities and Bifurcations in Solids, Structures and Soft Materials Chair(s): Yong-Zhong Huo	MS10: Damage and Fracture of Brittle and Quasi-Brittle Materials Chair(s): Da-Xu Zhang	MS2: Modeling Time-Dependent Behavior and Deterioration of Concrete Chair(s): Lin Wan-Wendner	MS14: Uncertainty Quantification and Reliability-based Performance Evaluation Chair(s): Zhen-Hao Zhang	MS17: Stability and Failure of Structures and Materials Chair(s): Xiang Yang Ji-Feng Xu	MS9: Reliability Analysis of Engineering Structures under Disastrous Excitations Chair(s): Jun Xu
10:40—10:55	A0121 (Invited): Wrinkling of Soft Biomaterials	A0978: Impact Fracture Simulation of Monolithic and Laminated Glass Using Hybrid Discontinua and Continua Method	A0042: Concrete Creep Modeling: Application to Slabs on Ground	A0131 (Invited): Analyzing Complex Systems under Epistemic Uncertainties	A0839 (Invited): Failure and Buckling Analyses of Composite Laminates with Cut-Outs: Theory and Experiments	A0022 (Invited): A Probabilistic Analysis of a Phenomenological Model for Structural Collapse Simulation
		Xing-Er Wang	Ya Wei			
10:55--11:10		A0857: Modelling of Damage and Fracture of Plain Weave Ceramic Matrix Composites under Uni-Aixal Tension	A0082: Numerical Module Development for the Entire Process of RC Deterioration due to Non-Uniform Corrosion			
	Bo Li	Da-Xu Zhang	Zhao-Zheng Meng	Michael Beer	Jian-Xiang Wang	Cheng Chen

Program: Day 3-Saturday, 3 Nov 2018

11:10--11:25	A0342: Photo-Responsive Surface Wrinkling Patterns	A0863: Prediction of Shear Damage Behaviour of Fibre-Reinforced Ceramic Matrix Tows	A0287: Age Dependent Shear Resistance of Reinforced and Prestressed Concrete	A0644: Probability Distrubution of the Time Interval Between Two Adyacent Random Events of the Wiener Process Crossing a Boundary	A0149: Frequency Analysis for Vibrating Bending Beams via a New Static Approach	A0824: Assessing the Spalling of Tunnel Linings Subjected to Fire Loading
	Cong-Hua Lu	Da-Xu Zhang	Lin Wan-Wendner	Zhen-Hao Zhang	Zhen-Yu Chen	Yi-Ming Zhang
11:25--11:40	A0250: Mechanics of Nanofibers Packing in Vesicles: Effects of Fiber Length, Radius, and Elasticity	A0866: Validation of the Combined FEM-DEM on Mode I and II Concrete Rupture Subjects to Semi-Circular Bending	A0708: A Theoretical Framework for Creep Effect Analysis of Axial Loaded Short CFST Columns under High Stress Levels	A0222: Multi Level Moving Particles Simulation for Reliability Assessment with Approximate Limite State Functions	A0586: Buckling of Beams Subject to Influence of Surface Stresses	A0349: Stochastic Dynamic Response Analysis and Reliability Assessment of Non-Linear Structures under Fully Non-Stationary Ground Motions
	Xin Yi	Xu-Dong Chen	Shi-Wei Li	Carsten Proppe	Feng Lin	Jun Xu
11:40--11:55	A0397: A Consistent Finite-Strain Plate Theory for Growth-Induced Deformations and Instabilities of Soft Material Samples	A0034: Influence of Asphalt Mixture Type on Strength Size Effect Statistics at Low Temperature	A0593: Probabilistic Model of the Yielding Strength for the Corroded Rebars	A0949: Structural Failure Mode Identification and Reliability Analysis based on Multi-Response Surface Method	A0380: PLY-GAP Effects on Buckling Behavior of Composite Conic Barrel by Automated Fiber Placement	A0347: Simulation of Stationary Non-Gaussian Vector Process within Wave-Passage Effect based on Spectral Representation Method
	Jiong Wang	Augusto Cannone Falchetto	Xiang-Ling Gao	Zhao Chen	Tian-Liang Qin	Yong-Xin Wu
11:55--12:10	A0054: Pattern Transitions in a Soft Cylindrical Shell		A0098: Concrete Shear Walls Affected by Alkali-Silica Reaction Part I: Testing	A0549: Study on Mechanical Properties and Damage Assessment for Collided Concrete	A0590: Thermal Postbuckling Behaviours of Functionally Graded Nanocomposite Plates	A0538: Impact of Initial Damage Path and Spectral Shape on Aftershock Collapse Fragility of RC Frames
	Fan Xu		Shamim Sheikh	X. Y. Liu	Yin Fan	Xiao-Hui Yu
12:20--13:30	Lunch (The 1st floor of Kingswell Hotel Sunshine Coffee Shop and the 3rd floor of Kingswell Hotel No.3 Room)					

Program: Day 3-Saturday, 3 Nov 2018

	Sino-French Center Room C201					
14:00--14:40	Plenary Lecture Chair(s): Prof. Roberto Ballarini					
	Mechanics of interfaces in FRP-strengthened structures Prof. Jin-Guang Teng - Southern University of Science and Technology, P.R.China					
	Sino-French Center Room C201	Sino-French Center Room C401	Yifu Building Room 113	Sino-French Center Room A401	Tongji University Zhonghe Building Room 1002	Tongji University Zhonghe Building Room 802
Session	MS3: Instabilities and Bifurcations in Solids, Structures and Soft Materials Chair(s): Xi-Qiao Feng	MS1: Cementitious Materials: Experiments and Modeling Across the Scales Chair(s): Bernhard Pichler	MS12: Dynamic Analysis and Seismic Performance of Structures under Strong Earthquake Ground Motions Chair(s): Ertugrul Taciroglu Yi-Qiang Xiang	MS14: Uncertainty Quantification and Reliability-based Performance Evaluation Chair(s): Michael Beer	MS17: Stability and Failure of Structures and Materials Chair(s): Zheng Li Ji-Feng Xu	MS9: Reliability Analysis of Engineering Structures under Disastrous Excitations Chair(s): Ding Wang
14:50--15:05	A0154 (Invited): Morphological Evolution of Buckle-Delamination: from Telephone Cord Blister to Beyond	A0919: Microstructural Characterization of the Spun Cast Concrete	A0105: Dimensional Seismic Responses of Shear-Flexural Beam and Self-Similar Interstory Drift Spectrum	A0915: Risk Priority Numbers for Various Failures in Bridges	A0681: Imperfections by design: interactive buckling and postbuckling in architected materials	A0563: Structural Reliability Analysis Using UQFEM Software
		Maciej Sobótka	Gui-Qiang Guo	Chandrasekhar Putcha	Nan Hu	Zi-Qi Wang
15:05--15:20		A0761: Time-Space Dependent Stability Analysis of Shallow Natm Tunnels with Discontinuity Layout Optimization	A0109: A New Approach to Design Explicit Time Integration Algorithm with Numerical	A0179: Efficient Bridge Lifetime Assessment by Traffic Load Model Updating and Subset Simulation	A0332: Characterization of nonlinear constitutive behavior of ceramic-based composite using digital image correlation	A0520: Seismic Fragility Analysis of Urban Road Network - A Case Study on Tangshan City
	Yong Ni	Yi-Ming Zhang	Shi Li	He-Qing Mu	Xiao-Hui JI	Ding Wang

Program: Day 3-Saturday, 3 Nov 2018

15:20--15:35	A0493: Pattern Formation in Curved Film-Substrate Systems	A0038: Macro-Scale Strength and Microstructure of ZrW2O8 Cementitious Composites with Tunable Low Thermal Expansion	A0567: Modeling and Performance Assessment of Base-Isolated Buildings	A0912: Analytical Solution for Local Buckling Strength of Square CFT Columns Subjected to Eccentric Compression	A0473: Characterization for Compression-Shear Combined Properties of a Composite Material	A0577: Seismic Reliability Analysis of Energy-Dissipation Bridge Structures Using Hamiltonian Monte Carlo Based Subset Simulation in Conjunction with Explicit Time Domain Dimensionality Reduction
	Michel Potier-Ferry	Yang-Bo Li	Nicholas Oliveto	Yu-ling Long	Ti-Ren He	Shao-Min Jia
15:35--15:50	A0061: A Modeling and Resolution Framework for Wrinkling in Hyperelastic Sheets at Finite Strain	A0283: Multiscale Thermomechanical Analysis of Reinforced Concrete Beams Subjected to Sudden Heating	A0355: Collapse Performance Assessment of Self-Centering Precast Concrete Walls with Different Post-Tensioning and Energy Dissipation Designs	A0753: A Polynomial Element Based Galerkin Approach for the Simulation of Multivariate Random Fields	A0384: Seismic Performance of Unreinforced Masonry Walls with Boundary RC Frame	
	Chen-Bo Fu	Hui Wang	Hao Wu	Xu-Fang Zhang	Young-Chan You	
15:50--16:10	Coffee Break (The 1st floor of Sino-French Center)					
Session	MS3: Instabilities and Bifurcations in Solids, Structures and Soft Materials Chair(s): Fan Xu	MS1: Cementitious Materials: Experiments and Modeling Across the Scales Chair(s): Yi-Ming Zhang	MS7: Non-deterministic modelling and uncertainty management in structural dynamics and vibroacoustics Chair(s): Michael Beer	MS14: Uncertainty Quantification and Reliability-based Performance Evaluation Chair(s): Hong-Zhe Dai	MS6: Damage modelling of engineering structures Chair(s): Lu Hai	MS15: Environmental Effects on the Properties of Cementitious Materials: Experiments, Modeling and Simulation Chair(s): Tao Li
16:10--16:25	A0089 (Invited): Morphable 3D Mesostructures and Microelectronic Devices by Multistable Buckling Mechanics	A0139: Strengthening Effect of Cementitious Materials Subjected to High-Dynamic Loading	A0439 (Invited): The Bhattacharyya Distance: A Novel Uncertainty Quantification Metric in Stochastic Sensitivity Analysis	A0944: Reliability Analysis of Seismic Capacity of Shear Wall Considering Possible Tension Failure and Random Eccentricity	A0169 (Invited): Concurrent Fatigue Crack Growth and Vehicle-Bridge Dynamics Analysis Using Time-based Sybcycle Formulation	A0953(Invited): Multi-Phase Modelling of Multi-species Transport in Cementitious Materials: In case of Electrochemical Rehabilitation
		Eva Binder		Yan-Biao Wang		

Program: Day 3-Saturday, 3 Nov 2018

16:25--16:40	A0089 (Invited): Morphable 3D Mesostructures and Microelectronic Devices by Multistable Buckling Mechanics	A0198: Multiscale Modeling of Cementitious Materials: From Hydration via Microstructure to Macroscopic Properties	A0439 (Invited): The Bhattacharyya Distance: A Novel Uncertainty Quantification Metric in Stochastic Sensitivity Analysis	A0558: A Novel Machine Learning - Based Method to Predict Member Buckling for Square Pyramid Space Grid Structure	A0169 (Invited): Concurrent Fatigue Crack Growth and Vehicle-Bridge Dynamics Analysis Using Time-based Sybcycle Formulation	A0953(Invited): Multi-Phase Modelling of Multi-species Transport in Cementitious Materials: In case of Electrochemical Rehabilitation
	Yi-Hui Zhang	Bernhard Pichler	Si-Feng Bi	Qian Zhang	Yong-Ming Liu	Qing-Feng Liu
16:40--16:55	A0433: Controllable Rolling and Configurable Bending in Flexible Nanomemrbanes	A0244: Investigation of the Shrinkage - Volume to Surface Ratio Relationship in Cement Considering Cracking	A0044: Structural Reliability and Reliability Sensitivity Analysis of Extremely Rare Failure Events by Combining Sampling and Surrogate Model Methods	A0540: Estimating Uncertainty in Limit State Capacities for Reinforced Concrete Frame Structures Through Pushover Analysis	A0879: Constitutive Modeling of Ductile and Brittle Failures of Semicrystalline Polymers	A0526: Experimental Research on Dynamic Characteristics of Crumb Rubber Concrete at Low Temperature
	Yong-Feng Mei	Yi-Ge Zhang	Peng-Fei Wei	Xiao-Hui Yu	Jia-Liang Le	Gang Xue
16:55--17:10	A0715: Electromechanical Catastrophe	A0691: Insight into the Role of Interfacial Bolts on the Structural Behavior of Segmental Tunnel Rings	A0323: Modeling the Asymmetric Dependent Soil Variables	A0203: Stochastic Stay Cable Force Modeling Using Monitoring Data from a Cable-stayed Bridge	A0477: Machine Learning based Multiscale Modeling of Backward Erosion Piping	A0805: Stochastic Dynamical Behaviors of Corrosion Reaction System in Concrete Subjected to External Sulfate Attack
	Tong-Qing Lu	Jiao-Long Zhang	Yi Zhang	Michael Hai-Jun Zhou	Alessandro Fascetti	Tao Li
17:10--17:25	A0026: Actuating Soft Materials in Surgery Robot Applications	A0736: Meso-Finite Element Fracture Anasysis for Fiber Reinforced Emulsified Asphalt - Cement Concrete	A0079: Model-Form and Parameter Uncertainty Quantification in Structural Vibration Simulation Using Fractional Derivatives	A0389: Prestressed Concrete Beams Failing due to Web-Crushing: Uncertainty and Reliability Analysis	A0827: Scaling Effects for Dynamic Responses with Application to Buried Arches Subjected to Internal Blast	A0812: Stochastic Modeling of Sulfate Ion Diffusion Coefficient at the Concrete-Solution Interface
	Bo Li	Jun Fu	Bao-Qiang Zhang	Oladimeji Benedict Olalusi	Sze Dai Pang	Shan-Shan Wang

Program: Day 3-Saturday, 3 Nov 2018

17:25--17:40	A0426: Edge Wrinkling of a Soft Ridge with Gradient Thickness	A0028: Performance of the Concrete Free from Steel Reinforcement	A0535: A Bayesian Method for Joint Parameter Optimal Estimation based on Power Spectral Density	A0830: Quantifying Post-disaster Functionality Losses and Recovery of Community Building Portfolios	A0451: Simulating Time-Dependent Quasi-Brittle Failures based on a Multilinear Releasing Mechanism of Viscous Force Fields	A0966: Research on Moisture Transport of Cement-based Materials Based on Low Field Nuclear Magnetic Resonance
	Yan Zhao	Jiang-Tao Yu	Zhang Yong	Nai-Yu Wang	Jin-Xing Liu	Xia Wu
17:40--17:55	A0483: Localized Bulging in an Inflated Bilayer Tube				A0651: Analysis of Seismic Collapse of High-Rise Structure under Near-Fault Pulse-Type Ground Motion	
	Yang Liu				Tian-Can Huang	
18:30--21:00	Banquet (The 15th floor of Shanghai Jinjiang Metropolo Hotel)					

Program: Day 4-Sunday, 4 Nov 2018

Time	Venue					
	Sino-French Center Room C201					
8:30--9:50	Plenary Lectures Chair(s): Prof. George Deodatis					
8:30--9:10	Analysis of Concrete Structures A Joint Research Project of Tongji University and Vienna University of Technology Prof. Herbert Mang - Vienna University of Technology, Austria; Tongji University, P.R. China					
9:10--9:50	Uncertainty Propagation from Materials Characterization to Modeling Prof. Lori Graham-Brady - Johns Hopkins University, USA					
9:50--10:10	Coffee Break (The 1st floor of Sino-French Center)					
	Sino-French Center Room C201	Sino-French Center Room C401	Yifu Building Room 113	Sino-French Center Room A401	Tongji University Zhonghe Buliding Room 1002	Tongji University Zhonghe Buliding Room 802
Session	MS18: Computational Modeling of Advanced Materials and Novel Structural Systems for Hazard Mitigation Chair(s): Mohamed Moustafa	MS12: Dynamic Analysis and Seismic Performance of Structures under Strong Earthquake Ground Motions Chair(s): Zheng He Di-Xiong Yang	MS7: Non-Deterministic Modelling and Uncertainty Management in Structural Dynamics and Vibroacoustics Chair(s): Jian-Bing Chen	MS14: Uncertainty Quantification and Reliability-based Performance Evaluation Chair(s): Da-Gang Lu	MS13: Damage and Failure Modeling and Analysis of Concrete and Structures Chair(s): Zhao-Dong Ding	GS4: Structural Mechanics and Simulation Chair(s): Hao Zhou
10:10--10:25	A0368: Section and Finite Element Analysis of Seismic UHPC Piers with High Strength Steel	A0112 (Invited): Recent Advances in Engineering Characteristics of Near-Fault Ground Motions and Seismic Effects of Building Structures	A0145 (Invited): A Robust Approach to Quantifying Forecasting Uncertainty Using Proxy Simulations	A0518 (Invited): Global Dynamic Seismic Reliability Analysis for RC Frame Structures Using NT-ANN	A0970 (Invited): An Equivalent Strain based Multi-Scale Damage Model of Concrete	A0259: A Parallel Spectral Element Method for the Simulation of Scalar Elastic Waves
	Mohamed Moustafa					Seungwook Youn
10:25--10:40	A0363: Multi-Physics Simulation on Passive Patch Antenna Sensor for Wireless Strain Measurement					A0267: A Numercal Study on the Thermo-Mechanical Response of a Composite Beam Exposed to Fire
	Dan Li	Di-Xiong Yang	Scott Cogan	Da-Gang Lu	Shi-Xue Liang	Moon Soo Kang

Program: Day 4-Sunday, 4 Nov 2018

10:40--10:55	A0729: Primary Structural Configuration Investigation of a Novel Coupling Arm Connecting Two Floating Structures	A0313: Features of Offshore Seismic Ground Motions Distinct from the Onshore	A0129: Dynamic Response of a Train-Bridge Intraction System due to Sudden Deceleration in High Speed Railway Systems	A0020: Robust Statistical Methods for Power Spectrum Estimation from Multiple Source Records	A0124: Multilevel Modeling of Fiber-Reinforced Concrete and Simulation of Cracking in Tunnel Lining Segments	A0310: Theoretical Study on Vibration of a Simply Supported Footbridge under Discrete Pedestrian Loading
	Tao Li	Qi Zhang	Xu-Zhao Lu	Marco Behrendt	Yi-Jian Zhan	Shih-Hsun Yin
10:55--11:10	A0321: Enhancing Seismic Performance of Porcelain Electrical Equipment Using Base Isolation	A0523: Dynamic Testing of a Full-Scale Frp-Retrofitted Reinforced Concrete Building Frame	A0414: Non-Probabilistic Model of Transmissibility Functions based on Complex Interval Arithmetic	A0440: Identification of Performance Degradation Model based on Standard Wiener Process	A0274: Numerical Investigation of Concrete Age Effect on Shear Load Capacity of Post-Installed Anchors	A0721: Non-Linear Numerical Analysis on Overall Process Mechanical Behavior of Quasi-Rectangular Segmental Tunnel Lining
	Wen Bai	Jiuk Shin	Meng-Yun Zhao	Xiao Wang	Roman Wan-Wendner	Zhen Liu
Session	MS18: Computational Modeling of Advanced Materials and Novel Structural Systems for Hazard Mitigation Chair(s): Mohamed Moustafa	MS12: Dynamic Analysis and Seismic Performance of Structures under Strong Earthquake Ground Motions Chair(s): Zheng He Di-Xiong Yang	MS5: Nonlinear Stochastic Structural Dynamics Methodologies for Complex Engineering Systems Chair(s): Jian-Bing Chen	MS14: Uncertainty Quantification and Reliability-based Performance Evaluation Chair(s): Da-Gang Lu	MS13: Damage and Failure Modeling and Analysis of Concrete and Structures Chair(s): Zhao-Dong Ding	GS4: Structural Mechanics and Simulation Chair(s): Hao Zhou
11:10--11:25	A0360: Characterization and Modeling of Adaptive Rubber Bearing	A0673: Seismic Vulnerability of Railway Network based on the Running-Trains Safety Evaluation	A0659: An Efficient Stochastic Complex Modal Analysis Technique for Nonclassically Damped and Nonlinear MDOF Structural Systems	A0423: Structural Failure Pattern Recognition and Reliability Analysis based on Multi-Response Surface Method	A0378: Analytical Model of Rocking Elements with Damaged Corners	A0467: Impact Location and Load Identification Using Deep Neural Networks
	Y. E. Ji	Cheng Yang	Ioannis P. Mitseas	Zhao Chen	Hao-Ran Cui	Jia-Ming Zhou

Program: Day 4-Sunday, 4 Nov 2018

11:25--11:40	A0671: System Level Analytical, Experimental and Hybrid Simulation of Resilient Highway Bridges	A0899: Multi-Scale Comprehensive Simulation of Concrete Shear Wall Models: Numerical Simulation	A0802: A Hybrid SEM–SM Method for Subway Random Dynamic Loads Induced by the Frequency-Dependent Dynamic Properties of Rail Pads	A0580: A New Fractional Moment Equations Method for Nonlinear Vibration Analysis	A0504: Development and Identification of Hysteresis Model for Reinforced Concrete Columns Failing in Different Modes	A0983: A B-Scan Subsurface Imaging of Ground Cavities Using an Elastic Wave Full-Waveform Inversion Method
	Selim Gunay	Jing-Ran He	Kai Wei	Rui-Jing Zhang	Xin-Liang Lyu	Boyoung Kim
11:40--11:55		A0008: Potential Risks on Using Disconnected Composite Foundation Systems in Active Seismic Zones	A0890: Stochastic Response Analysis of an Offshore Wind Turbine under the Excitations Represented by Stochastic Harmonic Function	A0583: A Kriging-Hdmr Metamodel Method for System Reliability Analysis of Structures	A0119: A Fracture Problem with a Surface Energy in the Steigmann-Ogden Form	
		Mohamed Elmasry	Yu-Peng Song	Kai-Xiang Zhang	Anna Zemlyanova	
11:55--12:10		A0293: Optimal Design of SMA Cable Restrainers for Seismic Protection of a LRB Isolated Simply Supported Highway Bridge				
		Shuai Li				
12:20--13:30	Lunch (The 3rd floor of Kingswell Hotel Ball Room)					
	Sino-French Center Room C201					
	Plenary Lecture Chair(s): Jian-Ying Wu					
14:00--14:40	Meshfree Methods: Progress Made After 20 Years and Future Directions Prof. Jiun-Shyan Chen – University of Californian, San Diego, USA					

Program: Day 4-Sunday, 4 Nov 2018

	Sino-French Center Room C201	Sino-French Center Room C401	Yifu Building Room 113	Sino-French Center Room A401	Tongji University Zhonghe Buliding Room 1002	Tongji University Zhonghe Buliding Room 802
Session	GS3: Wood Mechanics Chair(s): Jan-Willem G. van de Kuilen	MS16: Fluid-Structure Interactions and Flow-Induced Motions Chair(s): Ning Zhang	GS1: Stochastic Mechanics and Structural Reliability Chair(s): Wang-Ji Yan	MS8: Computational Modeling of Damage and Failure in Solids and Structures Chair(s): Jian-Ying Wu	MS13: Damage and Failure Modeling and Analysis of Concrete and Structures Chair(s): Chao-Lie Ning	GS4: Structural Mechanics and Simulation Chair(s): Tian-Can Huang
14:50--15:05	A0968: Variablity in Wood/Plant Anatomy Along the Scales	A0159: Wind-Induced Cladding and Structural Loads on Low-Rise Buildings with 4:12-Sloped Hip Roofs	A0227: Towards Stochastic Modeling of Tsunamis	A0392 (Invited): Mitigating Mesh Dependence of Stochastic Computation of Quasibrittle Fracture	A0604: Three-Dimensional Finite Element Modelling of Uhpfrc Jacket-Retrofitted Piers under Cyclic Loading	A0512: Ultimate Capacity of Bulge Formed T-Joints under Brace Axial Compression Excluding the Chord Length Effect
	Wolfgang Gard	Shuai Shao	Zhi-Heng Wang		Teng Tong	Fei-Long Nie
15:05 --15:20	A0308: Development of an Andvanced FE-Numerical Method for Strength Prediction of Timber Boards based on the Surface	A0442: Applications of Immersed Boundary Methods in Hydraulic Modeling	A0554: A Generic Framework for Probabilistic Damage Characterisation Using Ultrasonic Guided Wave in the Frequency Domain		A0635: Spatial Correlation in Disordered Heterogeneous Materials	A0595: Experimental and Numerical Studies of Resonance Vibration of Cables in a Footbridge Model under Biharmonic Excitation
	Ani Khaloian Sarnaghi	Ning Zhang	Wang-Ji Yan	Jia-Liang Le	Zhao-Dong Ding	Wojciech Pakos
Session	GS3: Wood Mechanics Chair(s): Jan-Willem G. van de Kuilen	MS16: Fluid-Structure Interactions and Flow-Induced Motions Chair(s): Ning Zhang	GS1: Stochastic Mechanics and Structural Reliability Chair(s): Wang-Ji Yan	MS8: Computational Modeling of Damage and Failure in Solids and Structures Chair(s): Jian-Ying Wu	GS5: Bio-Mechanics and Bone Mechanics Chair(s): Chao-Lie Ning	GS4: Structural Mechanics and Simulation Chair(s): Tian-Can Huang
15:20--15:35	A0955: Deformation Kinetics for Wood Mechanics	A0785: Mode Interactions of Deep-Sea Riser in Shear Flow	A0454: Multidimensional Stochastic Damage Model for Concrete under Fatigue Loading	A0757: Cracking Elements Method for Simulating Multiple Cracks	A0667: The Relation Between Corneal Hydration and Stiffness Improvement Becuase of the Corneal Crosslinking Treatment	A0903: Understanding Uncertainties from Cyclic Tests of Shape Memory Alloy Bars for Seismic Application
	Van de Kuilen Jan-Willem	Yuan-Cen Wang	Yan-Peng Wang	Yi-Ming Zhang	Hamed Hatami-Marbini	Jin-Peng Li

Program: Day 4-Sunday, 4 Nov 2018

15:35--15:50	A0957: An Investigation of The Dol Effect of Wood´in Tension Perpendicular oo Grain	A0747: Nonlinear Parametric Vibration Analysis of Radial Gates	A0751: A Fractional Moment Method for Reliability Analysis of Structures under the Spatially Variability	A0633: Phase Field Modeling of Hydraulic Fracturing in the Framework of the Theory of Porous Media	A0870: A 3-Dimensional Modelling Comparison of the Biomechanical Stability of Lateral Lumbar Interbody Fusion with Unilateral or Bilateral Fixation Method	A0164: Hybrid Intelligence for Solving Complex Engineering Problems: An Integrated Human and Machine Learning Approach
	En-Chun Zhu	Si-Yuan Wu	Xu-Fang Zhang	Chen-Yi Luo	Teng Zhang	Yong-Ming Liu
15:50--16:05	A0960: An Investigation of Fatigue Fracture of Wood due to Cyclic Moisture_Induced Stress	A0972: Actively-Controlled Turbulence Simulations and Their Effects on the Aeroelastic Properties of Typical Bridge Deck Sections		A0811: Stochastic Analysis of Polymer Composites Ruptures at Large Deformations Modeled by a Phase Field Method		
	Qiong-Yao Wu	Yu-Chao Lv		Jie Wu		
16:05--16:25	Coffee Break (The 1st floor of Sino-French Center)					

	Sino-French Center Room C201	Sino-French Center Room C401	Yifu Building Room 113	Sino-French Center Room A401	Tongji University Zhonghe Buliding Room 1002
Session	MS3: Instabilities and Bifurcations in Solids, Structures and Soft Materials Chair(s): Michel Potier-Ferry	MS12: Dynamic Analysis and Seismic Performance of Structures under Strong Earthquake Ground Motions Chair(s): Jing-Quan Wang Jiuk Shin	MS17: Stability and Failure of Structures and Materials Chair(s): Ji-Feng Xu Lim Chee Wah	GS2: Computational Mechanics Chair(s): Jia-Liang Le	MS4: Computer Vision-based Studies in Structural Health Monitoring Chair(s): Mohammad Jahanshahi
16:25--16:40	A0195: Interactions Between Topological Defect Nucleation and Boundary Branching in the Growth of Curved Crystals	A0016 (Invited): Output-Only Identification of Civil Engineering Systems	A0925(Invited): Strengthening, Failure and Twinning Mechanisms of Graphene/Copper Composites	A0063: Model Reduction Techniques for Dynamic Systems with a Large Number of Local Modes	A0372: System Identification and Seismic Response Monitoring of Large-Scale Bridge Models Using Target-Tracking Digital Image Correlation
	Long Ma			Xiao-Shu Zeng	Mohamed Moustafa

Program: Day 4-Sunday, 4 Nov 2018

16:40--16:55	A0318: The Amplitude-Frequency Response of Thin Composite Plate in the Thermal Environment	A0016 (Invited): Output-Only Identification of Civil Engineering Systems	A0925(Invited): Strengthening, Failure and Twinning Mechanisms of Graphene/Copper Composites	A0102: Group-Theoretic Exploitations of Symmetry in Computational Mechanics of Novel Prestressed Structures	A0387: Automatic Bolt Loose Detection based on Digital Image Processing Technology
	Jin-Ming Li	Ertugrul Taciroglu	Ning Hu	Yao Chen	Lin-Sheng Huo
16:55--17:10	A0174: Modeling and Simulation of the Electro-Mechanical Coupling Behavior of Liquid Crystal Elastomers	A0883: Dynamic Testing of a Full-Scale FRP-Retrofitted Reinforced Concrete Building Frame	A0776: Classification of Steel H-Shaped Cross-Sections under Combined Compression and Bending Considering Plate Interaction Effect	A0629: Implementation of a Mesh Sensitive-Less Approach for the Pseudo-Lower Bound Method	A0910: An Algorithm for Identification of Structural Parameters and Excitation Forces Using Noncontact Vision-based Displacement Measurements
	Yi-Wei Xu	Jiuk Shin	Xue-Song Hou	Michele De Filippo	Ying Lei
17:10--17:25	A0069: On the Wrinkling and Restabilization of Highly Stretched Rectangular Sheets	A0530: Simplified Model based on Spectrum Analysis for the Optimal Outrigger Location of High-Rise Buildings	A0247: Hazard-Independent Study of the Stability Sensitivity of the Low Rise Frame Systems Subjected to the Extreme Loading Conditions	A0661: Mechanical Properties of Filamentous Networks in Terms of Their Microstructure	
	Ting Wang	Li-Li Xing	Christopher L. Mullen	Hamed Hatami-Marbini	
17:25--17:40	A0216: Curvature Effect on Wrinkling and Restabilization of Highly Stretched Elastic Shells	A0851: Multiscale Random Fields-based Damage Modeling and Analysis of Concrete Structures	A0875: Buckling of Composite Plates with Reinforced Oval Holes	A0211: Weak Enforcement of Displacement Conditions in Fictitious Domain Finite Element Analysis	
	Yi-Fan Yang	Hao Zhou	Ling-Wei tang	Kai-Zhou Lu	
17:40--17:55		A0990: Theory and Verification for Calculation of Girder Bridge Overturning with Coupling of Rigid and Deformable Body Rotation	A0705: Soil Arching Effect Based Study on the Stress Distribution and Failure Mode of the Holes for Under-Excavation in Building Rectifying	A0031: Computation Application Development in Scientific Paradigm	
		Wei-Bing Peng	Qing-Xia Yue	Echefu Francis Emeka	

17:55--18:10		A0024: Analysis of the Bridge with Single Column by Performance and Reliability-based Seismic Design Method		A0188: Effect of Power Take-off Damping on Hydrodynamic Efficiency of an Oscillating Water Column Wave Energy Device	
		Yi-Qiang Xiang		Piyush Mohapatra	

Plenary Lectures

Zdeněk P. Bažant

Born and educated in Prague (Ph.D. 1963), Bažant joined Northwestern in 1969, where he has been W.P. Murphy Professor since 1990 and simultaneously McCormick Institute Professor since 2002, and Director of Center for Geomaterials (1981-87). He was inducted to NAS, NAE, Am. Acad. of Arts & Sci., Royal Soc. London; to the academies of Italy (lincei), Austria, Spain, Czech Rep., India and Lombardy; to Academia Europaea, Eur. Acad. of Sci. & Arts. Honorary Member of: ASCE, ASME, ACI, RILEM; received 7 honorary doctorates (Prague, Karlsruhe, Colorado, Milan, Lyon, Vienna, Ohio State); Austrian Cross of Honor for Science and Art 1st Class from President of Austria; ASME Medal, ASME Timoshenko, Nadai and Warner Medals; ASCE von Karman, Freudenthal, Newmark, Biot, Mindlin and Croes Medals and Lifetime Achievement Award; SES Prager Medal; RILEM L'Hermite Medal; Exner Medal (Austria); Torroja Medal (Madrid); etc. He authored eight books: Scaling of Structural Strength, Inelastic Analysis, Fracture & Size Effect, Stability of Structures, Concrete at High Temperatures, Concrete Creep and Probabilistic Quasibrittle Strength. H-index: 121, citations: 66,000 (on Google, incl. self-cit.), i10 index: 605. In 2015, ASCE established ZP Bažant Medal for Failure and Damage Prevention. He is one of the original top 100 ISI Highly Cited Scientists in Engrg. (www.ISIhighlycited.com). His 1959 mass-produced patent of safety ski binding is exhibited in New England Ski Museum.
Home: http://cee.northwestern.edu/people/bazant/

Design of New Materials and Structures to Maximize Strength at Probability Tail: A Neglected Challenge for Quasibrittle and Biomimetic Materials

Zdeněk P. Bažant
Northwestern University, USA

Abstract: In developing new materials, the research objective has been to maximize the mean strength (or fracture energy) of material or structure and minimize the coefficient of variation. However, for engineering structures such as airframes, bridges of microelectronic devices, the objective should be to maximize the tail probability strength, which is defined as the strength corresponding to failure probability 10-6 per lifetime. Optimizing the strength and coefficient of variation does not guarantee it. The ratio of the distance of the tail point from the mean strength to the standard deviation depends on the architecture and microstructure of the material (governing the safety factor) is what should also be minimized. For the Gaussian and Weibull distributions of strength, the only ones known up to the 1980s, this ratio differs by almost 2:1. For the strength distributions of quasibrittle materials, it can be anywhere in between, depending on material architecture and structure size. These materials, characterized by a nonnegligible size of the fracture process zone, include concretes, rocks, tough ceramics, fiber composites, stiff soils, sea ice, snow slabs, rigid foams, bone, dental materials, many bio-materials and most materials on the micrometer scale. A theory to deduce the strength distribution tail from atomistic crack jumps and Kramer's rule of transition rate theory, and determine analytically the multiscale transition to the representative volume element (RVE) of material, is briefly reviewed. The strength distribution of quasibrittle particulate or fibrous materials, whose size is proportional to the number of RVEs, is obtained from the weakest-link chain with a finite number of links, and is characterized by a Gauss-Weibull grafted distribution. Close agreement with the observed strength histograms and size effect

curves are demonstrated. Discussion then turns to new results on biomimetic imbricated (or scattered) lamellar systems, exemplified by nacre, whose mean strength exceeds the strength of constituents by an order of magnitude. The nacreous quasibrittle material is simplified as a fishnet pulled diagonally, which is shown to be amenable to an analytical solution of the strength probability distribution. The solution is verified by million Monte-Carlo simulations for each of fishnets of various shapes and sizes. In addition to the weakest-link model and the fiber-bundle model, the fishnet is shown to be the third strength probability model that is amenable to an analytical solution. It is found that, aside from its well-known benefit for the mean strength, the nacreous microstructure provides a significant additional strengthening at the strength probability tail. Finally it is emphasized that the most important consequence of the quasibrittleness, and also the most effective way of calibrating the tail, is the size effect on mean structural strength.

Herbert Mang

Born: January 5, 1942, Vienna, Austria; Dipl.-Ing., Civil Engineering, and Dr.techn., Vienna University of Technology (VUT) (1967 and 1970); University Assistant, VUT (1967-79); Fulbright Fellow (1971-72), Research Assistant (1973), Ph.D. (1974), all at Texas Tech; Max Kade Fellow, Cornell University (1975-76); Habilitation, VUT (1977); Visiting Research Associate, University of Tokyo (1979); Associate Professor, VUT (1979-83); UNIDO Field Expert, Zhengzhou Research Institute for Mechanical Engineering, China (1981); Prof., Head of Institute for Mechanics of Materials and Structures, VUT (1983-2010); Prof. Emer., VUT (10-2010-); National RPGE Chair Prof., Tongji Univ., Shanghai (2012-); Co-author of 8 books and 4 chapters of handbooks, co-editor of 16 books, author (co-author) of 226 journal papers and 280 proceedings papers, book chapters, etc.; 12 International/Foreign Prizes (including 2 Foreign Decorations) and 12 National Prizes (including 3 Young Investigator Awards and 4 Decorations); 6 Honorary Doctorates (Technical University of Cracow, Innsbruck, Kiev, Leoben, Prague, and Vilnius); 1 Honorary Professorship, Tongji University, Shanghai; Foreign Assoc. of CAE and NAE; Member of 3 European Academies of Sciences (and Arts) and of 15 National/Regional Academies of Sciences/ Engineering (in Austria, Croatia, the Czech Republic, Georgia, Germany, Hungary, Poland (Warsaw and Cracow), Portugal, Slovakia, in the Ukraine, and in the USA); President, Austrian Academy of Sciences (2003-06); Vice-President, Austrian Science Council (2010-2015).

Multiscale Analysis of Concrete Structures

A Joint Research Project of Tongji University and Vienna University of Technology

Herbert Mang
Vienna University of Technology, Vienna
Tongji University, P.R. China

Abstract: The paper contains a report about a joint research project of Tongji University and Vienna University of Technology. Its title reads as "*Bridging the Gap by Means of Multiscale Analysis*". The project was inspired by the tunnel, *bridging the gap* between the two parts of the Hongkong-Zhuhai-Macao Bridge (HZMB), *bridging the gap* between cities on opposite sides of the mouth of the Pearl River into the South Chinese Sea. The project stretches over the time period 2015-2019. It is financially supported by the Austrian Science Fund and the China Scholarship Council. The aim of the project is an assessment of the added value of multiscale analysis of tunnel segments by means of a comparison of results with the ones from experimental tests and with results from conventional structural analysis.

The following four topics will be treated in the lecture:

(1) microstructural analysis of impact and blast loading of tunnel linings
(2) multiscale analysis of thermal stresses in cement linings due to sudden temperature changes
(3) experiments and finite element modeling of concrete in Mechanized Tunneling with special emphasis on concrete hinges
(4) experimentally supported multiscale structural analysis of a segmental tunnel ring

The project has

- convincingly proved the added value of multiscale structural analysis,
- underlined the importance of both material tests and large-scale structural experiments and, last but not least,
- enabled participation of highly qualified students from both Tongji University and Vienna University of Technology in challenging research work in the framework of their doctoral thesis.

It is a good example of a meaningful blend of *material mechanics of concrete and multiscale analysis of concrete structures.*

Hai-Yan Hu

Prof. Haiyan Hu received Ph. D. in Solid Mechanics from Nanjing University of Aeronautics and Astronautics (NUAA), China in 1988. Then, he was a Humboldt Researcher Fellow at University of Stuttgart, Germany and a Visiting Professor at Duke University, USA successively. He received Professorship in Mechanics in NUAA in 1994, served as President of NUAA from 2001 to 2007, and President of Beijing Institute of Technology from 2007 to 2017.
Prof. Hu has made recognized contributions to the nonlinear dynamics and control of aerospace structures, including the delayed control of flexible structures, the nonlinear vibration isolation of missile stabilizers, the active flutter suppression of aircraft wings, and the deployment dynamics of space antennas. He was elected Fellow of The Chinese Academy of Sciences in 2007, Fellow of The World Academy of Sciences (TWAS) in 2010, and awarded Honorary Doctor of Science by Moscow State University, Russia in 2015 and by University of Reading, UK in 2016, respectively.

Engineering Dynamics of Soft Machines

Haiyan Hu
Beijing Institute of Technology, P.R. China

Abstract: The concept of soft machines covers a great variety of advanced industrial products, such as a soft robot handling fragile objects, a deployable solar sail and an airplane with morphing wings. Those soft machines are mainly composed of soft bodies, which are made of soft materials, including polyimide, silicon elastomer and electro-active polymer, so as to adapt to complex environments or missions. Furthermore, the soft bodies undergo not only large deformations, but also overall motions and frictional contacts with themselves or their environments.
This lecture presents the dynamic study on soft machines in the frame of multibody system dynamics. The study focuses on the efficient dynamic modeling of the geometrical nonlinearity of coupled overall motion and large deformation of a soft body, the physical nonlinearity of hyper-elasticity and elasto-plasticity, and interactional nonlinearity of frictional contacts or even entanglements of soft bodies, as well as the efficient dynamic computation algorithm of rigid-soft multibody system governed by a set of differential-algebraic equations of very high dimensions. The lecture illustrates the proposed approach via three case studies, i.e., the locomotion of a soft quadrupedal robot, the spinning deployment of a solar sail of spacecraft, and the deployment of a mesh reflector of satellite antenna, as well as the corresponding experimental studies.

Jiun-Shyan (JS) Chen

J. S. Chen is currently the Inaugural William Prager Chair Professor of Structural Engineering Department and the Director of Center for Extreme Events Research at UC San Diego. Before joining UCSD in October 2013, he was the Chancellor's Professor of UCLA Civil & Environmental Engineering Department where he served as the Department Chair during 2007-2012. J. S. Chen's research is in computational mechanics and multiscale materials modeling with specialization in the development of meshfree methods. He is the Past President of US Association for Computational Mechanics (USACM) and the Past Present of ASCE Engineering Mechanics Institute (EMI). He has received numerous awards, including the Computational Mechanics Award from International Association for Computational Mechanics (IACM), ICACE Award from International Chinese Association for Computational Mechanics (ICACM), the Ted Belytschko Applied Mechanics Award from ASME Applied Mechanics Division, the Belytschko Medal, U.S. Association for Computational Mechanics (USACM), among others. He is the Fellow of USACM, IACM, ASME, EMI, ICACM, and ICCEES.

Meshfree Methods: Progress Made After 20 Years and Future Directions

Jiun-Shyan (JS) Chen
University of Californian, San Diego, USA

Abstract: In the past two decades, meshfree methods have emerged into a new class of computational methods with considerable success. In addition, a significant amount of progress has been made in addressing the major shortcomings that were present in these methods at the early stages of their development. For instance, essential boundary conditions are almost trivial to enforce by employing the techniques now available, and the need for high order quadrature has been circumvented with the development of advanced techniques, essentially eliminating the previously existing bottleneck of computational expense in meshfree methods. Given the proper treatment, nodal integration can be made accurate and free of spatial instability, making it possible to eliminate the need for a mesh entirely. Meshfree collocation methods have also undergone significant development, which also offer a truly meshfree solution. This presentation will give an overview of major progresses made in the field, the application to many challenging engineering mechanics problems, and the future directions of this research area.

Jin-Guang TENG

Professor Jin-Guang Teng is a Vice-President of Southern University of Science and Technology (SUSTech) and a Chair Professor at both SUSTech and The Hong Kong Polytechnic University (fractional appointment). He is an Academician of the Chinese Academy of Sciences, a Fellow of the Hong Kong Academy of Engineering Sciences and a Corresponding Fellow of the Royal Society of Edinburgh.

Professor Teng has conducted research on a wide range of topics across the broad field of structural engineering, including the structural use of fibre-reinforced polymer (FRP) composites in construction as well as steel and thin-walled structures. He has authored/co-authored over 200 SCI journal papers, leading to over 9,500 citations and an H-index of 50 according to the Web of Science Core Collection. Many of his research findings have been adopted by relevant design codes/guidelines in China, Australia, Europe, the United Kingdom and the United States. His research contributions have been recognized by many awards and prizes, including the State Natural Science Award of China, Distinguished Young Scholar Award from the National Natural Science Foundation of China, the IIFC Medal from the International Institute for FRP in Construction (IIFC), and the State-of-the-Art of Civil Engineering Award from the American Society of Civil Engineers.

Mechanics of interfaces in FRP-strengthened structures

Jin-Guang TENG
Southern University of Science and Technology, China

Abstract: The performance of structures, particularly concrete structures, can be substantially enhanced through the external bonding of fiber-reinforced polymer (FRP) reinforcement in the form of thin laminates. In such an FRP-strengthened structure, the interface between the FRP laminate and the existing structure plays a key role in determining its behavior and strength. Indeed, extensive laboratory testing has demonstrated that failure of FRP-strengthened structural members often occurs by debonding of the FRP laminate from the existing structural member in a number of distinct modes. In this presentation, the speaker will provide a brief review of the intensive research undertaken over the past two decades on these debonding failure problems and a summary of the current understanding of interfacial mechanics in FRP-strengthened structural members that has resulted from this research. The major part of the presentation will be concerned with interfaces in FRP-strengthened concrete members, but interfaces in FRP-strengthened steel members will also be given due attention. The specific aspects to be covered include: (1) fundamental behavior of bonded interfaces; (2) classification of debonding failure modes; (3) debonding failure mechanisms and processes; (4) finite element and theoretical modelling issues; (5) design methods. The presentation will end with a brief discussion of future research needs.

Lori Graham-Brady

Lori Graham-Brady is Professor and Chair of the Civil Engineering Department at Johns Hopkins University, with secondary appointments in Mechanical Engineering and Materials Science & Engineering. She is also the Associate Director of the Hopkins Extreme Materials Institute. Her research interests are in computational stochastic mechanics, multiscale modeling of materials with random microstructure and the mechanics of failure under high-rate loading. She has been heavily involved in EMI, as a member of the EMI Board of Governors, as an Associate Editor for the Journal of Engineering Mechanics, and as the Chair of the EMI Probabilistic Methods Committee. She has received a number of awards, including the Presidential Early Career Award for Scientists and Engineers (PECASE), the Walter L. Huber Civil Engineering Research Prize, and the William H. Huggins Award for Excellence in Teaching.

Uncertainty propagation from materials characterization to modeling

Lori Graham-Brady
Johns Hopkins University, USA

Abstract: Three-dimensional microstructures collected by experimental characterization provide both statistical information and the basis for computational models, which allows us to analyze heterogeneous materials at small length scales. However, the collection of such three-dimensional microstructural data commonly relies on destructive techniques, such as serial sectioning, and such methods often provide no quantitative measure of the accuracy of the digital microstructure in representing the true physical specimen. This makes quality assessment of the data sets difficult and it poses a challenge to identify which characterization parameters will produce optimal efficiency in the data collection process while maintaining an acceptable level of error in the resulting data. To address this question, this presentation describes a computational method that was developed to simulate serial sectioning data collection, based on a digital representation of a material, called a phantom. By simulating the data collection and data processing protocols of user defined parameters such as resolution, slice thickness, dwell time, polishing method, etc. the effect of each on error propagation can be tracked relative to the fully understood digital phantom. Then by varying each parameter the effects can be studied individually and provide bounds on both the contributions of each parameter to the error as well as the total error introduced through the experimental process. This provides a quantitative method for comparing the relative trade off between experimental parameters such collecting data at a very high resolution vs. collecting data over a large volume. Ultimately these measures are then utilized as part of an objective function to optimize the selection of experimental parameters. An example of optimization of experimental data collection parameters for the acquisition of an 3D Electron Backscatter Diffraction (EBSD) data set demonstrates how the error in computational models can be reduced.

Abstracts

MS1: Cementitious Materials: Experiments and Modeling across the Scales

A0013- Road guard innovative use of plastic waste material in redesigning road curbs

Ahiati Ebenezer[a]

[a] Student, Kwame Nkrumah University of Science and Technology,

ahiatiebenezer@gmail.com

There are many deteriorated roads in Ghana, West Africa. These deteriorations mostly occur due to erosion from rainfall and cause several depressions in roads, mostly along the edges. This can have adverse effects, such as accidents. An alternative to protecting road edges after construction is the use curbs. However, traditional curbs are expensive and using them as means of protection for a road system is not feasible. Hence, this paper introduces a cost effective and reliable approach of using a polymer-based product molded into grids, Road Guard, since reconstruction of roads after a short while of usage is too expensive for a developing country. The Road Guard will be produced from recycling plastic waste, which is another major problem in the country, and will be converted into grids through melting and casting. It will have an arbitrary length of 20.669 feet (6.3 meters) with a channel at about every 19.029 feet (5.8 meters) to allow for rain water run-offs. Installation will be carried out by placing the road guard at the edges of the road and filling it with the road construction material (concrete, bitumen, etc.) before, during or after road construction. After a cost analysis it was obtained that equivalent length of Road Guard compared to the curbs was cheaper. Apart from solving the issue with the roads, the plastic waste menace in the country will also be addressed since they will be used to produce the device. In concluding, the Road Guard is still in the conceptual stages and hence needs a lot of testing. However, one major setback is the lack of funding to produce a working model even though a prototype has been produced from cardboard for subsequent installation tests.

A0028- Performance of the concrete free from steel reinforcement

YU Jiangtao[a], Ye Junhong[b], ZHAN Kaili[c]

[a] College of Civil Engineering, Tongji University, Shanghai China, email: yujiangtao@tongji.edu.cn

[b] College of Civil Engineering, Tongji University, Shanghai China

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Ultra-high ductility cementitious composites (UHDCC) developed by the authors has the tensile strain capacity close to that of steel. To explore the feasibility of using plain UHDCC in construction, a series of experiments were conducted at material, structural member and structure scales, including mechanical properties of UHDCC, the behavior of plain UHDCC beams and columns under monotonic and lateral cyclic loadings, and the responses of composite UHDCC frame under various earthquake excitations. The test results indicated that the average tensile strain capacity of UHDCCs reached 12%, exceeding the strain capacity required for steel used to reinforce concrete structure. Additionally, UHDCC even exhibited strain-hardening characteristics under compression. The results from four-point bending test demonstrated the outstanding performance of UHDCC beams under lateral cyclic loading. The plain UHDCC beam has close load bearing capacity to the reference RC beams with the steel reinforcement ratio of 1.0 % but much better flexural ductility. RC frame (reinforcement ratios of columns were about 2.0%) and plain UHDCC frame were comparatively tested on a shaking table. The plain UHDCC frame survived a series of seismic excitations with the peak ground acceleration ranging from 0.105g to 1.178g, and exhibited better energy-dissipating capacity associated with consistently increasing damping ratio under earthquake excitations. The performance of the plain UHDCC frame fulfilled the requirements in Chinese seismic code, i.e., no damage under the frequently occurring earthquake, being repairable under the design-based earthquake, and no collapse under the rarely occurring earthquake. Generally, this series study from material scale to structure scale confirmed the feasibility of construction with plain UHDCC.

A0038- Macro-scale strength and microstructure of ZrW_2O_8 cementitious composites with tunable low thermal expansion

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Concretes with engineered thermal expansion coefficients, capable of avoiding failure or irreversible destruction of structures or devices, are important for civil engineering applications, such as dams, bridges and buildings. In natural materials, thermal expansion usually cannot be easily regulated and an extremely low thermal expansion coefficient (TEC) is still uncommon. Here we propose a novel cementitious composite, doped with ZrW_2O_8, showing a wide range of tunable thermal expansion coefficient from 8.65×10^{-6}°C^{-1} to 2.48×10^{-6}°C^{-1}. Macro-scale experiments are implemented to quantify the evolution of the thermal expansion coefficients, compressive and flexural strength over a wide range of temperature. Scanning Electron Microscope(SEM) imaging was conducted to quantify the specimens' microstructural characteristics including pores ratio and size. It is shown that the TEC of the proposed composites depends on the proportion of ZrW_2O_8 and the ambient curing temperature. Macro-scale experimental results and microstructures have a good agreement. The TEC and strength gradually decrease as ZrW_2O_8 increases from 0% to 20%, subsequently fluctuates until 60%. The findings reported here provide a new routine to design cementitious composites with tunable thermal expansion for a wide range of engineering applications.

A0139- Strengthening effect of cementitious materials subjected to high-dynamic loading

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The compressive strength of concrete increases with increasing speed of dynamic loading. Fischer et al. developed an elasto-brittle model to account for this strengthening effect. The main idea of this model is that cracks nucleate as soon as the quasistatic strength is reached and that high-dynamic strengthening manifests itself in the increase of the compressive stress during the evolution of the failure mode. Fischer et al. corroborated the predictive capabilities of the model by comparing model predictions with experimental data from high-dynamic tests of specific cement paste and mortar specimens. Continued exemplary validation is the topic of the first part of this contribution. Model predictions are compared with additional experimental data from high-dynamic tests of specific mortar and concrete cylinders. In the second part, the model of Fischer et al. is combined with the validated multiscale model for the quasi-static compressive strength of concrete by Königsberger et al., to study the influence of hardening of the concrete used for the immersed tunnel of the Hong Kong-Zhuhai-Macao-Bridge on its dynamic compressive strength. In the third part, the model is extended towards consideration of the high-dynamic tensile strength.

A0198- Multiscale modeling of cementitious materials: from hydration via microstructure to macroscopic properties

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The philosophy of multiscale modeling of heterogeneous materials is to resolve their microstructure, in a step-by-step fashion, down to a scale at which material constituents are found that exhibit material constants rather than evolving material parameters. Concrete, for instance, is a matrix-inclusion composite, with aggregates and sand representing inclusions which are embedded in a cement paste matrix. The properties of cement paste are not constant, because they depend on its composition and maturity, i.e. on the initial water-to-cement mass ratio and the degree of hydration. Thus, cement paste is modeled as a matrix-inclusion composite, with residual cement particles representing inclusions which are embedded in a hydrate foam matrix. The hydrate foam is a highly randomized arrangement of capillary pores (which are filled either by water or air) and hydration products which are needle-shaped and isotropically-oriented in space. As for the hydration products, material constants can be introduced, which allow for prediction of the hydration-driven evolutions of stiffness, creep, and strength of cementitious materials. The present contribution provides an overview over related multiscale modeling activities carried out at the Institute for Mechanics of Materials and Structures at TU Wien – Vienna University of Technology. Concretes are considered to consist of aggregates, sand, cement, water, air, and hydration products. The latter are the "glue" of the microstructure, the only creeping constituent, and the weakest links of the microstructure of cementitious materials. Thus, they are essential for the macroscopic stiffness, creep, and strength of cementitious materials. Eshelby-problem-based homogenization schemes of continuum micromechanics allow for bridging all the scales between the hydration products and the macroscopic application scale of cementitious materials. It can be shown that the behavior of hydration products is governed by simple physical laws. The latter translate, because of microstructural interactions with other constituents, into a complex macroscopic behavior of cementitious materials.

A0244- Investigation of the shrinkage - volume to surface ratio relationship in cement considering cracking

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Standardized shrinkage models for concrete incorporate a function which depends on the volume to sample surface ratio (V/S). This function stems from experimental observations and has been rationalized based on non-uniform pore humidity distributions during drying, which depend on V/S. Such shrinkage stress distributions should also lead to different crack development as a function of V/S. By conducting companion 3D X-ray Microscope (XRM) scans and shrinkage studies of cements of different V/S ratios, the impact of crack development on this size effect relationship is studied. The XRM scans can resolve drying contours to validate computed pore humidity distributions. Furthermore, the scanned internal surface area (incorporating pores and cracks) provides a more accurate representation of drying surface. By integrating the internal surface area into the computed pore humdity distributions, it is possible to understand how cracking and porosity play a role in the shrinkage to V/S relationship.

A0278- Dynamic property identification of shaking table test about existing R.C

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Because low connection strength and high stiffness between infilled masonry wall and frame, the infilled would separate from major structure members or cracked in less earthquake influence, then the dynamic properties of specimen had changed significantly. So that the white noise used for specimen had a small amplitude, and a short duration. Large deviations existed in frequency domain method at high frequencies, indicating less accuracy of frequency domain method. System identification of the specimen were extracted from floor accelerations under the white noise excitations by the eigensystem realization algorithm method and nature excitation technique . Damping characteristics of the specimen were identified. It is shown that eigensystem realization algorithm method is effective and sensitive to higher modes respectively. And it can identify the crack behavior of infilled masonry wall. High mode vibration is easy to occur for existing R.C. frame.

A0283- Multiscale thermomechanical analysis of reinforced concrete beams subjected to sudden heating

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Steel-reinforced concrete structures are subjected to sudden temperature changes, e.g., in the exceptional load case of a fire. At the macrostructural scale, kinematic constraints are hindering the deformations associated with the thermal eigenstrains. Thus, thermal stresses are induced. The constraints originate from three sources: the support conditions of statically indeterminate structures, the geometric incompatibility of macroscopic eigenstrains resulting from non-stationary heat conduction, and the mismatch of thermal expansion coefficients of the steel and the concrete. At the microstructural scale of plain concrete, self-equilibrated stresses prevail even in the absence of macroscopic kinematic constraints. These stresses result from the mismatch of the thermal expansion coefficients of the cement paste and the aggregates. The present contribution is inspired by a potential fire inside the immersed tunnel of the Hong Kong-Zuhai-Macao-Bridge. The overhead slabs of the segments of the tunnel are idealized as reinforced concrete beams. Their bottom surfaces are subjected to sudden heating. Three-dimensional analyses provide insight into macroscopic and microscopic stress states. To this end, modern multiscale material models for concrete are used to quantify the elastic stiffness and the thermal expansion coefficient of the concrete used for the segments of the aforementioned immersed tunnel. These macroscopic properties serve as input for thermomechanical Finite Element simulations of the steel-reinforced concrete beams. The obtained macroscopic temperature distributions and stress fields are postprocessed in the context of top-down analysis which allows for quantifying the microscopic average stresses experienced by the cement paste and the aggregates. Two sources of microscopic stress fluctuations are identified: macro-to-micro stress concentration, governed by stiffness contrasts, and the incompatibility of the microscopic fields of thermal eigenstrains, governed by the mismatch of the thermal expansion coefficients of the cement paste and the aggregates.

A0327- Influence of steel fibre, electrical waste copper fibre and E-glass fibre on mechanical properties of concrete

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Fibre-reinforced concrete (FRC) contains fibrous material which increases its structural integrity. The application of sporadic fibres to concrete altogether upgrades its essential characteristics, for instance, static flexural strength, influence quality, elasticity, malleability and flexural stiffness. Filaments are added to cement to control breaking because of plastic shrinkage and to drying shrinkage. This paper exhibits the use of steel fibre, electrical waste copper fibre and E-glass fibre of various percentages of volume fractions such as 0.25%, 0.5%, 1% and 1.25% incorporated in concrete. Mechanical properties such as compressive strength, split tensile strength and flexural strength tests were conducted for normal concrete and fibre reinforced concrete for a curing period of 7 days, 14 days and 28 days. In addition to that modulus of elasticity of concrete for various percentages of fibre content was calculated for a curing period of 28 days. The test results of fibre reinforced concrete were compared with normal concrete to obtain the optimum dosage of fibres used.

A0685- Effects of loading rates and temperatures on pullout responses of basalt yarn and fabric embedded in cementitious matrix

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Pullout response of basalt fabric embedded in cementitious matrix specimens was investigated under different loading rates and temperatures. Two types of pullout specimens, namely basalt single yarn and basalt fabric were tested. The pullout behaviors of specimens were evaluated in terms of initial pullout force, peak pullout force, work of pullout and work of peak force (Fig.1). Pullout velocity ranges from static (5.0×10^{-5} m/s) to dynamic (1.0, 2.0, 3.0 and 4.0 m/s); And dynamic responses were studied under four temperatures (-25, 0, 25, 50 ˚C) with different loading rates. The experimental results indicated that the pullout velocity, temperature and the fabric form can significantly affect the pullout responses. There exist a typical three stages during pullout loadings (Fig.1). At each temperature, the initial and peak pullout forces under dynamic loading are higher than the static ones. In addition, the pullout work and peak pullout work appear to be improved with increasing loading rate under each temperature. On the other hand, when the pullout velocity is constant, the initial pullout force, peak pullout force, work of pullout and work of peak force decreased with increasing temperatures. While the pullout work and peak pullout work appear to be improved with increasing pullout velocities under each temperature.

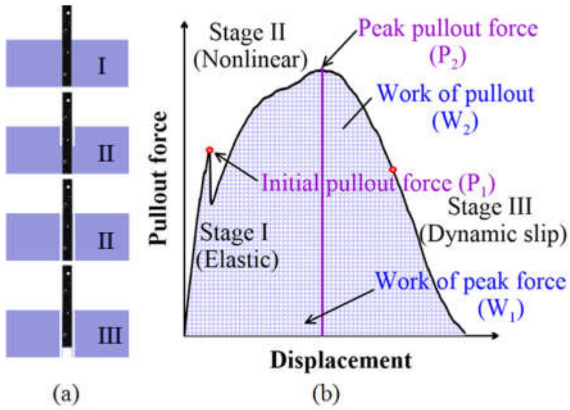

Fig. 1. Schematic of (a) three stages of the pullout process and (b) defined parameters to characterize the pullout responses under loading.

A0691- Insight into the role of interfacial bolts on the structural behavior of segmental tunnel rings

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Steel bolts are frequently used to connect neighboring segments of segmental tunnel rings. Once the bolts become active in tension, they increase the local bending stiffness and the local bearing capacity of the joint. In order to gain more insight into the role of interfacial bolts on the overall structural behavior of segmental tunnel rings, structural sensitivity analyses of two similar tunnel rings, one with unreinforced joints and the other one with bolted joints, are carried out. They involve combining nonlinear interface models with transfer relations representing analytical solutions of the governing equations of the linear theory of slender circular arches. The sensitivity analyses refer to determination of the elastic limit and of the bearing capacity of the segmental tunnel rings subjected to ground pressure. The analyses have shown that interfacial bolts (i) decrease the elastic limit intensity of ground pressure, (ii) improve the serviceability of segmental tunnel rings, because they ensure the position stability of the lining, (iii) are mandatory for overall structural equilibrium in case of markedly anisotropic ground pressure, and (iv) significantly increase the bearing capacity of segmental tunnel rings. In order to verify these conclusions, real-scale tests of three tunnel rings, one without interfacial bolts, one with new bolts, and one with corroded bolts, were carried out. The experimental investigations have confirmed the conclusions listed above. This corroborates the usefulness of the presented model for structural analysis of segmental tunnel rings and provides the motivation to employ it for future structural analysis accounting for durability of interfacial bolts.

A0736- Meso-finite element fracture anasysis for fiber reinforced emulsified asphalt –cement concrete

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PVA fibers was used to improve the flexural tensile strength and crack resistance for Fiber Reinforced Emulsified Asphalt–Cement Concrete(FREACC). Three-point bending test and uniaxial compression test showed that PVA fiber could significantly improve the macroscopic flexural tensile strength and fracture energy of the mixture, which had an increase more than 100% and 50%, but had little effect on the compressive strength and elastic modulus, which had an increase about 3%. In meso scale,FREACC could be considered as three phases which were aggregates, fiber-asphalt cement mortar, and pores.Based on the two-dimensional image digitization and bilinear cohesive zone constitutive relation,the meso-finite element fracture model could be established by inserting two-dimensional zero-thickness cohesive interface elements into the interface between different phases. Uniaxial tensile fracture and dynamic cracking of three-point bending beam were simulated,then the effect of PVA fibers on fracture toughness was discussed. The numerical simulation value of fracture energy was slightly larger than the experimental value, and the meso-fracture analysis was in good agreement with the macroscopic test results. The results of microfracture analysis also depicted that the interface between aggregate and asphalt mortar was a weak phase, where the fracture started from the interface. And PVA fiber could effectively enhance the tensile strength of the mixture and delay the crack propagation. The critical fracture load and the corresponding mid-span displacement of meso-numerical simulation were slightly smaller than the experimental values, but the difference of tensile strength was not obvious. The numerical simulation value of fracture energy was slightly larger than the experimental value, but the meso-fracture analysis was in good agreement with the macroscopic test results, demonstrating that the two-dimensional meso-fracture model was relatively accurate under uniaxial loading and three-point bending conditions.

A0761- Time-space dependent stability analysis of shallow natm tunnels with discontinuity layout optimization

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Shallow tunnels constructed by New Austrian Tunnelling Method potentially experience stability problems caused by inappropriate excavation speed or supporting procedures. Stability of the sections of these tunnels are time-space dependent, referring to the hydration processes of shotcrete, shapes of the tunnels and excavation speed.

In this work, we implement the multiscale model of hydrating shotcrete into the framework of discontinuity layout optimization, which is capable of efficiently obtaining the factor of safety and the corresponding failure mechanism of tunnel section. Meanwhile, convergence-confinement method is used for accounting the 3-dimensional effect in 2-dimensional analysis, providing time-space dependent stability assessments of these tunnels.

A0887- Mechanical performance of GFRP sandwich panels with stiffen webs

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This paper presents the details of a research program that was conducted to evaluate the one-way bending behavior of glass fiber reinforced polymer (GFRP) sandwich panels. The panels consist of GFRP skins with a foam-GFRP web core. An experimental study were carried out to study the effect of the skin and web thickness, the web height and the web space. The results demonstrate that compared to the only foam-core sandwich panels, a maximum of approximately 230% increase in the ultimate bending strength can be achieved. Meanwhile, the bending stiffness and energy dissipation can be enhanced respectively. A comparison of the experimental and analytical results showed that the analytical model accurately predicted the ultimate bending strengths deflections of the panels under four-point bending. Furthermore, the finite element analysis was conducted to simulate the bending behavior considering the bond performance of the face sheets and foam core.

A0919- Microstructural characterization of the spun cast concrete

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The aim of the work was to prepare the procedure for determining selected microstructure properties of the spun concrete with particular emphasis on the variation of these properties with the distance R from the outer edge of the member. The research was carried out using three different testing methods: nanoindentation, X-ray micro computed tomography (mCT) and 2D optical scanning. Obtained results allowed to characterize quantitatively following features of concrete internal microstructure: the distribution of aggregate throughout the member cross-section, the variability of mechanical parameters of the mortar with the distance R and the spatial distribution of the pores.

The analysis of aggregate distribution on the coordinate R was based on the results of optical scanning. Surface preparation of the concrete samples for scanning included grinding, acid etching and matrix dyeing. Aggregate segmentation from the images was made using digital image processing techniques. Morphometric analysis included, among others, determination of the volume fraction and local thickness of the aggregate.

In order to determine the mechanical parameters of the mortar (cement matrix together with fine aggregate), the nanoindentation method was utilized. A series of tests was carried out with CSM (Anton Paar) TTX-NHT apparatus equipped with Berkovich tip. Several measuring grids were set within the mortar at arbitrary locations corresponding to different values of R distance. Each of the grids included 100 imprints spaced at 50 μm. The results of the performed tests allowed to estimate average values of the hardness HIT and the indentation modulus MIT. Furthermore, applying deconvolution method allowed to estimate the fraction of the fine aggregate in mortar φ and to calculate the average hardness and average indentation modulus for the cementitious matrix and the aggregate separately.

The analysis of the pores distribution throughout the concrete volume was based on the 3D imaging by mCT. Bruker Skyscan 1172 scanner was utilized to acquire a set of projections. Image reconstruction was performed using Bruker NRecon software based on the Feldkamp algorithm. Since the grayscale values in mCT depend mostly on the material density one can assess the variation of average material density with the coordinate R. To characterize the spatial arrangement of the pores, they were first segmented by thresholding. Next, the binary images of the pores was analyzed. The pore space was presented in a three-dimensional model and quantitative analysis was performed.

MS2: Modeling Time-Dependent Behavior and Deterioration of Concrete

A0042- Concrete creep modeling: application to slabs on ground

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Moisture warping of concrete slab occurs as a long process due to the slow transportation nature of moisture in concrete materials. And thus creep, as a time dependent property of concrete, will inevitably affect the performance of slab on ground during this process. In this study, the effect of concrete creep is considered in pavement slab for analyzing moisture warping, warping stress, and the total stress under traffic loads. A method is proposed to calculate the time-dependent warping deformation and stress developments in concrete slab on ground. This method uses the sequential coupled hygromechanical finite element analysis and incorporates concrete creep model which is capable of considering the relative humidity effect. The effect of environment relative humidity, the design parameters, including concrete type, slab size, thickness, bounding condition with the base, and the age of concrete exposed to drying are investigated on the slab warping and stress considering the creep effect. It is found that concrete creep has a significant effect on slab warping and stresses. It is of importance to consider creep effect in design and analyzing deformation and stress generated in concrete pavement slabs, particularly when a moisture gradient exists in slab.

A0082- Numerical module development for the entire process of RC deterioration due to non-uniform corrosion

This study presents a mathematical model to depict each sub-process of reinforcement corrosion and their coupling effect based on the physical mechanisms of corrosion electrochemical reaction. Then, a physical-chemical-electro-chemical-mechanical multi-physics coupled comprehensive numerical module is developed to simulate the entire process of the corrosion-induced deterioration of RC structure; and the reduction of the load-carrying capacity of the RC structure versus exposure time can be given directly. The distribution of corrosion products on the surface of the steel reinforcement will be determined automatically, without having to be preset in advance. To predict the expansion pressure of concrete and the evolution of cracking pattern caused by non-uniform corrosion, a new smeared rust layer method is first proposed here. Several sets of experimental data were compared with the prediction by the numerical model for its verification.

A0093- Concrete shear walls affected by alkali-silica reaction part ii: modeling

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A procedure for nonlinear analysis of reinforced concrete structures affected by alkali-silica reaction (ASR) is presented. Two distinct time-dependent mechanisms are considered: the magnitude of the expansion, and the deterioration in the mechanical properties of the concrete. With these mechanisms implemented within the framework of finite-element programs developed for the analysis of membrane and three-dimensional structures, a smeared rotating-crack macro-modeling approach was applied to the analysis of ASR-affected shear walls tested under reversed-cyclic loading. The modeling techniques employed are detailed, as well as the factors affecting the computed response of the specimens. The sensitivity studies carried out identify several mechanisms that had a notable effect on the behavior. Based on the results presented herein, the modeling procedures described are found to be useful for the capacity assessment of deteriorated shear walls due to ASR.

A0098- Concrete shear walls affected by alkali-silica reaction part i: testing

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Reactive aggregates have been used in nuclear power plant structures in North America and elsewhere. Nuclear structures, in general, are heavily reinforced and often prestressed. Although ASR has been extensively studied over the years, available information on the effects of ASR on such structures is limited.

The experimental structural part of this research program is focused on testing of reinforced concrete walls made with ASR concrete and evaluating their performance against similar control walls that exclude reactive aggregates. A total of six walls were constructed, four made with ASR concrete and two with normal concrete. All the walls and accompanying small specimens such as cylinders and prisms were conditioned in a specially-constructed high temperature and high humidity chamber to accelerate the reaction and deterioration. This paper will present results from these walls that were tested in three phases under lateral displacement excursions while simultaneously subjected to axial load thus simulating seismic loads. In the first phase, after about 6 months of conditioning, the ASR wall was found to have about 14% higher capacity than normal wall although the ASR concrete strength and stiffness values were much lower than those of normal concrete. In the final phase after the exhaustion of ASR reaction, the ASR shear wall showed significantly less ductile behaviour compared to the normal wall and similar ASR walls tested in low damage phase. Ductility and ultimate lateral displacement of the walls were considerably reduced as ASR expansion progressed.

A0117- Modeling corrosion of reinforcement in concrete: accelerated vs. Natural corrosion

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Chloride-induced corrosion of steel reinforcement in concrete is one of the major causes for deterioration of reinforced concrete structures. Therefore, to predict durability of RC structure it is important to have a numerical tool, which is able to predict corrosion processes and their consequences for the structural safety. The main problem in formulating such models is quantifying controlling parameters for processes before and after depassivation of reinforcement.

The first objective of the present contribution is to validate the recently developed 3D chemo-hygro-thermo-mechanical model for concrete by means of an extensive experimental program, which includes tests under natural and laboratory controlled conditions. Particular attention is paid in characterizing the parameters of the hysteretic moisture model as well as the concrete conductivity.

The experiments related to the corrosion of steel reinforcement in concrete are usually carried out under accelerated conditions. The results of such experiments are then used in the formulation of design formulas. However, there can be a large difference between accelerated and natural corrosion. For instance, the corrosion products are significantly different, i.e. the expansion factor of corrosion products in case of accelerated corrosion is much smaller than in the case of natural corrosion. Moreover, distribution of corrosion over the reinforcement surface for the same geometry can be different. To illustrated these differences numerical study for the beam-end specimen with stirrups is performed for both cases. The specimen is first exposed to accelerated and natural corrosion. Subsequently, the main reinforcement bar is pulled-out out from the specimen to investigate the influence of the corrosion induced damage on the pull-out capacity. To verify the model, the results of accelerated corrosion are also compared with the available experimental results. It is clearly demonstrated that there are significant differences between the results obtained for accelerated and natural corrosion. Especially the position and variation of corrosion rate over the main reinforcement and stirrups are rather different. Therefore, the experimental results obtained under accelerated corrosion conditions should be used in the practice with special attention.

A0287- Age dependent shear resistance of reinforced and prestressed concrete

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Conventional finite element software and associated numerical models are typically used to analyze the mechanical behavior of structural scale concrete beams. However, they lack the ability to account for the heterogeneity of concrete or aging and deterioration effects. This paper introduces a comprehensive computational framework to model the behavior of reinforced and prestressed concrete beams under shear load. The framework consists of a discrete particle model incorporating effects from concrete aging, creep, shrinkage and prestress loss. Five-meter long concrete beams with full reinforcement and different prestress levels were tested under shear loads. Material tests of the concrete on various ages, including unconfined compression, uniaxial tests to measure modulus of elasticity, splitting tests, and fracture tests were carried out. Concrete creep and shrinkage measurements were also conducted to study their effect on prestress loss and consequently the shear response. The model constructs the beam with concrete as discrete particles and the steel rebars/tendons as beam elements. The concrete behavior is defined by constitutive laws with its material properties calibrated based on standard experimental tests. The behavior of reinforced rebars and prestressing tendons follow the elasto-plastic law of typical steel with known Young's modulus and yielding strength. The rebar beam elements and solid concrete elements interact with each other using penalty constraints. Before the shear load is applied, creep and shrinkage losses of concrete are evaluated, of which the parameters were calibrated based on the experimental measurements. The results of the predictive shear simulations for the reinforced and prestressed beams resemble those of the tested specimens including but not limited to the force-displacement responses, the failure types, and the crack patterns. With the well-calibrated and validated aging framework, the shear resistance of the prestressed concrete members can be accurately predicted.

A0593- Probabilistic model of the yielding strength for the corroded rebars

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Corrosion of the rebar is the major trigger of the crack of the cover, the degradation of the bond performance and the bearing capacity of the rebar. Therefore, the bearing capacity will be decreased and even the failure mode of the RC members may change from the ductile failure to the brittle failure. The degradation of the bearing capacity and the time-dependent reliability of reinforced concrete members can be predicted accurately only if the variety of the yielding strength of the corroded rebar has been acquired. In this paper, 1706 test data collected from 31 references were classified into three groups according to the cause of the corrosion which were constant current accelerated corrosion(CCAC), accelerated corrosion test in simulated environment(ACTSE) and in-suit corrosion of the practical RC members(ISCA). Based on the existing research, the yielding strength of the unstainable part of the corroded rebar is the same as the normal rebar. Accordingly, the minimum cross-sectional area of the corroded rebar at the different corrosion rate is the key issue to obtain the bearing capacity of the corroded rebar.

By using Lilliefors test, the abnormal data were deleted. The probability distribution model of the minimum normalized section area k of corroded steel bars of the three cases follows normal distribution. According to the analyzed results, it is found that the change of the mean value of k_{ISCA} is minimal with the increase of the corrosion rate, while the mean value of k_{ACTSE} decreased the most. Thereby, when CCAC and ACTSE methods are adopted to simulate the corrosion of the rebar, the normalized minimum section area k should be revised by the factors presented in the paper. Meanwhile, the distribution of the mean value of k_{ISCA} is more scattered when the corrosion rate increase. The presented probabilistic model of the yielding strength for the corroded bars was verified by using the confidence interval of 50% and 95%. When the confidence interval is 50 percent, more than half of the data was in the confidence interval. Almost all of the data is in the confidence interval when the confidence interval is 95 percent. It is proved that the probability distribution model of k_{ISCA} proposed in this paper is accurate and reliable, and has good applicability. Moreover, the bearing capacity of a RC beams were calculated due to the different corrosion rate of the longitudinal bars and the stirrups. It is proved that the failure mode of the RC beams can change from the flexural failure to the shearing failure.

A0708- A theoretical framework for creep effect analysis of axial loaded short CFST columns under high stress levels

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Due to its excellent mechanical performances, axial loaded concrete-filled steel circular tube (CFST) columns have been widely used in structural engineering. As an important long-term behavior of CFST structures, creep has an obvious nonlinear property under high the stress levels, i.e., creep is not linearly dependent on the stresses, which makes the influence of creep more complicated. In this study, to analyze the impacts of nonlinear creep effect on the behavior of axial loaded short cfst columns, a complete theoretical framework for coupling analysis of 3D creep effect and material nonlinearity was presented. First, to simulate the plasticity and damage evolution of concrete core under high stress levels, a new concrete plasticity damage model with uniform constraint (UCCDP) was established. Next, based on the UCCDP and creep Possion ratio, a 3D nonlinear creep analysis method and the corresponding numerical analysis method were established, which was implemented into the ABAQUS secondary platform. Finally, by comparing the predicted results with experimental results in different stress levels, this approach for predicting the creep of axial loaded short CFST columns has exhibited satisfactory accuracy.

MS3: Instabilities and Bifurcations in Solids, Structures and Soft Materials

A0026- Actuating soft materials in surgery robot applications

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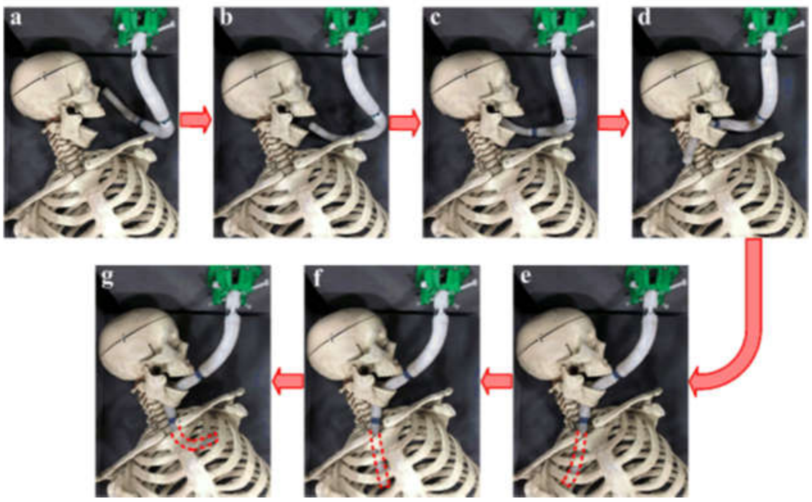
Conventional surgical robot are in straight-bar shape and made of rigid materials mostly, which fail to adapt to the minimally invasive surgical operation using natural orifices. Therefore, we develop a flexible surgical robot based on soft materials. Multi-DOF deformation and variable stiffness abilities via electro-pneumatic actuation and fiber jamming techniques, is presented. The integrated manufacturing process of the manipulator unit is developed. An experimental test system is set up to obtain the nonlinear relationships between the bending deformation, output force of the pneumatic artificial muscle actuator and the air pressure, by eliminating the instability. The relationships between anti-bending ability of a single unit and negative pressure, fiber arrangement and fiber density are further studied. The optimized design scheme is obtained. Within a complex system, the multi-DOF deformation in bypass, the tracking and the stiffness tunability of the manipulator are demonstrated.



A0054- Pattern transitions in a soft cylindrical shell

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Instability patterns of rolling up a sleeve appear more intricate than the ones of walking over a rug on floor, both characterized as systems of uniaxially compressed soft film on stiff substrate. This can be explained by curvature effects. To investigate pattern transitions on a curved surface, we study a soft shell sliding on a rigid cylinder by experiments, computations and theoretical analyses. We reveal a novel postbuckling phenomenon involving multiple successive bifurcations: smooth-wrinkle-ridge-sagging transitions. The shell initially buckles into periodic axisymmetric wrinkles at the threshold and then a wrinkle-to-ridge transition occurs upon further axial compression. When the load increases to the third bifurcation, the amplitude of the ridge reaches its limit and the symmetry is broken with the ridge sagging into a recumbent fold. It is identified that hysteresis loops and the Maxwell equal-energy conditions are associated with the coexistence of wrinkle-ridge or ridge-sagging patterns. Such a bifurcation scenario is inherently general and independent of material constitutive models.

A0061- A modeling and resolution framework for wrinkling in hyperelastic sheets at finite strain

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Wrinkles are commonly observed in uniaxially stretched rectangular hyperelastic membranes with clamped-clamped boundaries, and can disappear upon excess stretching. Here we develop a modeling and resolution framework to solve this complex instability problem with highly geometric and material nonlinearity. The main advantages of this framework include the generality for both compressible and incompressible materials, ease of programming, high precision and efficient continuation predictor. Moreover, various compressible or incompressible models can be systematically derived based on 3D strain energy potentials, e.g., Saint-Venant Kirchhoff, neo-Hookean, Mooney-Rivlin, Gent model and Gent-Gent model. Based on the proposed approach, effect of different incompressible constitutive models on the post-buckling response is quantitatively investigated, which shows limited influence on bifurcation diagrams. However, for compressible materials, Poisson's ratio plays a critical role in the wrinkling and restabilization behavior. We find that smaller Poisson's ratio makes later onset of wrinkling, lower amplitude and earlier disappearance of wrinkles. Besides, severe strain-stiffening phenomena are explored by accounting for phenomenological models such as Gent model and Gent-Gent model. Efficiency and accuracy of the method were examined by comparing with experimental, numerical and analytical benchmarks.

A0069- On the wrinking and restabilization of highly stretched rectangular sheets

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Wrinkles are commonly observed in uniaxially stretched rectangular sheets with clamped-clamped boundaries, and can disappear upon excess strtching. Here we explore this wrinkling and restabilization behavior both analytically and numerically. Effect of different constitutive models, i.e., Saint-Venant Kirchhoff, neo-Hookean and Mooney-Rivlin, on the post-buckling response are investigated, which shows rather limited quantitative influence on bifurcation diagrams. Poisson's ratio, however, plays a crucial role in the wrinkling and restabilization behavior. We find that smaller Poisson's ratio makes later onset of wrinkling, lower amplitude and earlier disappearance of wrinkles. In particular, when Poisson's ratio is below a threshold, no wrinkles occur, which can be explained by the decreasing transverse compressive stresses with respect to the reducing Poisson's ratio. Futhermore, based on the Koiter buckling theory, we have semi-analytically predicted secondary bifurcation points for the first time, through looking into the sign change of the quadratic terms in potential energy. Both theoretical buckling and secondary bifurcation points are in good agreement with finite element results.

A0089- Morphable 3D mesostructures and microelectronic devices by multistable buckling mechanics

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Three-dimensional (3D) structures capable of reversible transformations in their geometrical layouts have important applications across a broad range of areas. Most morphable 3D systems rely on concepts inspired by origami/kirigami or techniques of 3D printing with responsive materials, sometimes referred to as 4D printing. The development of schemes that can simultaneously apply across a wide range of size scales and with classes of advanced materials found in state-of-the-art microsystem technologies remains a grand challenge. This talk introduces a set of concepts for morphable 3D mesostructures in diverse materials (e.g., device-grade silicon, metals and polymers) and fully formed planar devices, including integrated electronic systems with high performance capabilities, spanning length scales from micrometers to millimeters. The approaches rely on elastomer platforms deformed in different time sequences to elastically alter, with engineering control, the 3D geometries of supported mesostructures via controlled processes of non-linear mechanical buckling. Comprehensive studies of multi-stability and corresponding energy landscapes in this context establish general design strategies. Demonstrations include experimental and theoretical investigations of over 20 examples, including mesostructures that can be reshaped between different generalized and recognizable geometries as well as those that can morph into three or more distinct states. Two functionally reconfigurable microelectronic devices, including an adaptive radio frequency circuit and a concealable electromagnetic device, provide examples of these concepts.

A0121- Wrinkling of soft biomaterials

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Biological materials often exhibit diverse morphologies, which can arise from either physiological or pathological growth. In this study, we combine theoretical analysis, numerical simulations, and experimental observation to elucidate how these morphologies are driven and dictated. Taking biofilms and mucosae as two typical examples, we show that residual stresses resulting from differential growth of biological materials are able to trigger surface wrinkling, which leads to various patterns. Phase diagrams are established to demonstrate the roles of thickness, elastic moduli, and interface bonding in regulating these wrinkling patterns. It is found that geometrical curvature and interfacial delamination can further enrich surface wrinkling. Our study highlights the role of mechanics in sculpting biological morphogenesis.

A0154- Morphological evolution of buckle-delamination: from telephone cord blister to beyond

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Understanding and controlling spontaneous complex nature's pattern formation is of broad interest in both scientific and engineering communities. High residual compressive stress in thin film-substrate systems usually causes structural and functional failures via buckling instability. In particular, they could buckle and delaminate away from the substrate, and exhibit complex buckle-delamination patterns, such as straight-sided, circular, ring-like, telephone cord or network-like blisters. In this talk, we focus on elucidating some universal morphological features of such telephone cord blisters and beyond via a combination of theoretical analysis, numerical simulation and experimental validation. How interface sliding and ridge cracking on various buckling instability modes and how these instabilities evolve into complex buckle-delamination patterns observed in our experiments are discussed.

A0174- Modeling and simulation of the electro-mechanical coupling behavior of liquid crystal elastomers

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Liquid crystal elastomers (LCEs) are weakly cross-linked polymers with liquid crystal mesogenic units and can exhibit liquid crystallinity. They are a type of soft active/smart materials that can have large spontaneous deformations in response to external stimulus and provide some functions that we need. LCEs could be polarized under electric fields, and the director of LC units can rotate then drive the polymer network to deform. So, LCEs exhibits interesting electro-mechanical coupling behavior. Other attributes of them include fast response and low cost. The deformation and electric polarizability of LCEs are couple with each other.

Based on the variational principle, we have derived the relevant constitutive and governing equations including the equations for the electric field induced LC director reorientation. We use this model to analyze and simulated deformations of LCE samples under electric-mechanical loading. The results indicated that when the initial alignment is uniform, the sample of LCE stripe exhibit uniform deformation under electric fields. Note that there is a critical electric field intensity at which the initially perpendicularly oriented LC director will bring instability and start to reorient. We call it the Freedericksz transition in LCE. If the initial alignment is nonuniform, the stripe can bend. In both cases, the behavior of deformations depend strongly on the initial alignment. Therefore the behavior of LCE samples could be regulated through proper design of the initial alignment.

A0195- Interactions between topological defect nucleation and boundary branching in the growth of curved crystals

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Topological defect nucleation and boundary branching in crystal growth on curved surface are two typical elastic instabilities driven by curvature induced stress, and separately discussed in the past. In this work they are simultaneously considered during crystal growth on a sphere. Phase diagrams with respect to curvature of the sphere, size, edge energy and stiffness of the crystal for the equilibrium crystal morphologies are achieved by theoretical analysis and validated by Brownian dynamics simulations. The simulation results further demonstrate the detail of morphological evolution by the transition and interplay between these two different stress relaxation modes. Topological defect nucleation and boundary branching not only compete each other and but also coexist in a range of combinations of the factors. Clarification of the interaction mechanism provides better understanding of various curved crystal morphologies for their potential applications.

A0216- Curvature effect on wrinkling and restabilization of highly stretched elastic shells

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Rectangular sheets with clamped-clamped boundaries can wrinkle upon uniaxial stretching and then revert to flat state upon excess loading. One may wonder what would happen on a curved shell? To investigate the curvature effect, we explore an open cylindrical shell under axial stretching, both experimentally and numerically. Our results indicate that the curvature plays an important role in the wrinkling and restabilization behavior. Curvature makes the peak and valley of wrinkles not symmetric, which shows a global-local coupling instability phenomenon. Besides, compared with planar geometry, curvature delays the appearance of wrinkles, while it makes the secondary bifurcation of restabilization much earlier. There exists a critical maximum value of the curvature to buckle the shell. Beyond this value, no wrinkles occur during axial stretching. Hyperelastic constitutive models (e.g., neo-Hookean and Mooney-Rivlin laws) and silicon rubber membranes are used in numerical simulations and experiments, respectively. The results can promise a novel direction to control the wrinkling instability of membranes.

A0250- Mechanics of nanofibers packing in vesicles: effects of fiber length, radius, and elasticity

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Cellular packing of one-dimensional nanomaterials, including natural cytoskeletal microtubules, actin filaments, synthetic nanotubes and nanowires, is of fundamental interest to the understanding of a wide range of cell activities, including cell shape control, cell movement, cell division, and nano-cytotoxicity. To understand the underlying mechanics of cellular/intracellular packing, we perform theoretical analyses and molecular dynamics simulations to investigate how the morphology and mechanical behaviors of a lipid vesicle are regulated by encapsulated nanofibers of different lengths, finite radii, and elasticity. As the rod length increases, the vesicle evolves from a sphere into different shapes, such as a lemon, a conga drum, a cherry, a bowling pin, or a tubular shape for long, thick, and stiff nanofibers. Moreover, we establish a packing phase diagram based on three distinct vesicle morphologies, including a non-axisymmetric dumpling-shaped vesicle with a strongly curved nanofiber, a cherry-shaped vesicle with a tubular membrane protrusion enclosing a significant portion of the nanofiber, and an axisymmetric lemon-shaped vesicle with a pair of protruding tips induced by the encapsulated nanofiber.

A0298- A state space method for onset of surface instability of graded soft materials

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Surface instability widely exists in nature and has been exploited for a range of applications. In this study, based on the governing equations and by discretizing the material properties into piecewise constant functions, a state space method is developed to solve the eigenvalue problem and predict the critical condition for onset of surface instability of graded hydrogel layers and graded elastic cylinders. For the hydrogel system, the state space solutions for homogeneous hydrogel layers, hydrogel bilayers, and continuously graded hydrogel layers are presented. For graded elastic cylinders, the state space solutions for a thin cylindrical shell, a bilayer on a soft cylinder, and exponentially graded elastic cylinders are obtained. The present solutions are compared with the analytical solutions and/or finite element results. In particular, a transition of the critical buckling mode for a soft cylinder covered by a bilayer is illustrated clearly by the present method. In contrast to the finite element method, the state space method is a semi-analytical approach with good convenience and higher computational efficiency for arbitrarily graded materials.

A0318- The amplitude-frequency response of thin composite plate in the thermal environment

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This paper deals with the dynamic response of a thin composite plate under a harmonic excitation in a thermal environment using incremental harmonic balance method (IHB). The nonlinear governing equations of the motion is developed based on the Kirchhoff hypothesis and von-Karman geometric non-linearity. Galerkin's method is utilized to derive the nonlinear governing equation of the problem with cubic nonlinearities associated with mid-plane stretching. An incremental arc-length method combined with a cubic extrapolation technique is adopted to trace the amplitude-frequency response curve. The periodic solutions and the stability are investigated using the IHB method. The solution of amplitude-frequency curve has been validated by the comparison of the results obtained by the IHB method and the numerical method. Variation of amplitude-frequency response curve and dynamic equilibrium position of thin plate with different temperature rising and same external excitation are presented. The results demonstrate that the combination of thermal deformation and the temperature rising governs the dynamic response. As the temperature increases, the transition of a hardening-spring type nonlinear dynamic response to a softening-type in the post-critical region due to two stable equilibria for the thin composite plate in the thermal environment has been presented. Furthermore, the dynamic behavior is becoming complicated as the external excitation frequency is close to the natural frequency of plate, which contains the typical resonance, super-harmonic, sub-harmonic resonance and the combination of them.

A0342- Photo-responsive surface wrinkling patterns

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Recently stimuli-responsive surface microstructures have attracted increasing interest owing to their wide applications. Here we report the dynamic modulation of surface instability-driven surface patterns on photo-sensitive film/substrate systems by introducing azo-containing functional groups. The influences of the substrate, the incident light intensity, and light polarization on surface wrinkling behavior have been investigated. Different photoresponsive properties of the azo-containing film are exploited to accumulate/release the bilayer compressive stress, and induce the reversible switching between surface wrinkling and dewrinkling states, which has been supported by the theoretical results. We take advantage of the characteristics of our light-responsive composite system for the application of all-optical reversible writing/erasure of (confidential) information, smart windows, and well optically-regulated gratings, as demonstrated here. This light control strategy coupled with surface wrinkling is expected to furnish the use of azopolymers in the area of smart surface fabrication which can find diverse novel applications in smart display, optoelectronic devices, and sensors, etc.

A0397- A consistent finite-strain plate theory for growth-induced deformations and instabilities of soft material samples

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Growth of soft biological tissues with thin plate forms (e.g., leaves, petals, wings of insects and skin) can be commonly observed in nature, during which the soft tissues usually undergo large deformations and exhibit various morphological instabilities. To properly study the growth deformations of soft tissues or other kinds of soft material samples, a suitable plate model is desired. In the present work, a novel finite-strain plate theory for growth-induced large deformations is developed. This plate theory was established within the framework of nonlinear elasticity, taking into account the growth effects and the elastic incompressibility. Derivation of the plate theory contains the following steps: 1) formulate the 3D governing system of the plate sample through variational approach, which includes the mechanical equilibrium equation and the constraint equation of incompressibility; 2) expand the unknown functions in terms of the thickness variable, and establish the recursion relations of the expansion coefficients from the mechanical equilibrium equation and the constraint equation; 3) derive the 2D vector plate equation from the lower and the upper boundary conditions in the 3D governing system; 4) propose the associated edge boundary conditions for the plate equation and derive the weak formulation for future numerical calculations. It can be verified that the plate equation system is consistent with the original 3D governing system to $O(h^2)$. To show the validity of the plate theory, two examples regarding the growth-induced deformations and instabilities in thin hyperelastic plates are studied. Some analytical results are obtained in these two examples, which can be used to describe the large deformations and reveal the instability properties of the thin plates. Furthermore, the results obtained from the current plate theory are compared with those obtained from the classical FvK plate theory, from which the advantages of the current plate theory can be demonstrated.

A0426- Edge wrinkling of a soft ridge with gradient thickness

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We investigate the edge wrinkling of a soft ridge with gradient thickness under axial compression. Our experiments show that the wrinkling wavelength undergoes a considerable increase with increasing load. Simple scaling laws are derived based on an upper-bound analysis to predict the critical buckling conditions and the evolution of wrinkling wavelength during the post-buckling stage, and the results show good accordance with our finite element simulations and experiments. We also report a pattern transformation triggered by the edge wrinkling of soft ridge arrays. The results and method not only help understand the correlation between the growth and form observed in some natural systems but also inspire a strategy to fabricate advanced functional surfaces.

A0433- Controllable rolling and configurable bending in flexible nanomembranes

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Rolled-up nanomembranes can take advantage of strain-engineering and form into three dimensional (3D) tubular structures for various applications including lab-on-a-chip, micro-/nanomachines, optical microcavity, sensors and actuators. Extensive attention has been focused on their strain engineering, control and process related to bending behaviors. Here we will introduce the method and process of rolled-up nanotech. With specified materials and process adopted, history-dependent rolling and configurable bending will be demonstrated for diamond helical structures and stimuli-responsive actuators. We believe that nanomembrane origami (e.g. rolling, bending and stretching) could offer an exciting platform for 3D mesostructures and their applications.

A0483- Localized bulging in an inflated bilayer tube

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Gent model is believed to be an excellent model for rubber material, where an important parameter J_m signifies the maximum extensibility. It turns out that a rubber tube made of Gent material cannot bulge for small J_m. In this talk, we consider a bilayer tube consisting of Gent materials. By virtue of a bifurcation condition derived for a single-layer tube of arbitrary thickness, we study the localized bulging of the bilayer tube. Our result suggests a possible way to prevent localized bulging by bonding a layer of specified thickness which cannot bulge inside or outside. Furthermore, the theoretical prediction is validated by finite element analysis. Accordingly, the applicability of the bifurcation condition is also confirmed. On the other hand, both volume control and pressure control problems are discussed, and the effects of the modulus ratio and thickness ratio on the critical pressure P_{cr} triggering a bulging or critical volume V_{cr} are investigated. For the pressure control problem, we find that a larger P_{cr} attains if the stiff part of the bilayer increases or one layer becomes stiffer. However, the case of volume control is different. It is found that V_{cr} is a non-monotone function of the percentage of the stiff part. All theoretical results are validated by the corresponding numerical ones using ABAQUS. Finally, we study the growth and propagation of the localized bulging employing the finite element method. It turns out that the effects of geometrical and material parameters on the maximum axial stretch and propagation pressure are similar to those on the critical pressure and volume.

A0484- Wrinkling of dielectric elastomer membranes

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A pre-stretched sheet, being partly covered with electrodes on both of its sides, and the ratio of the electric activating area is set as ?, will wrinkle under an electric activation. In this work, a computational model to characterize the wrinkling is proposed. Based on this model, some critical values, such as the critical voltage, applied stretch, et al. can be determined. The relation between the critical values and the number of wrinkles are also analyzed.

A0493- Pattern formation in curved film-substrate systems

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Stress-induced pattern formation and pattern selection of thin film/substrate systems have motivated a lot of researches during the last fifteen years. Most of the recent papers focus on planar film/substrate bilayers and only few are concerned with curved geometry. In this talk, we study the curvature effect on the buckling and post-buckling of such structures, especially cylindrical and spherical systems, from theoretical to numerical points of view. The behavior of such structures associating a stiff film and a soft core is investigated by using a 3D finite element model, the film being discretized by thin shell elements. As for pure shell structures (i.e. without a core), the instability scheme is loading and geometry-dependent. In the case of an axially compressed cylindrical pure shell, the buckling modes are known to be diamond-like and the buckling response is subcritical and highly imperfection-sensitive. The same scheme holds with a soft core, but the response becomes supercritical and the mode axisymmetric with a stiffer core. It is established that the influence of the core is governed by dimensionless parameters,$C_s=(R/h_f)^{3/2}E_s/E_f$ in axial compression and $C_{th}=(R/h_f)^{3/4}(L/h_f)^{3/2}E_S/E_f$ in the case of a thermal shrinkage of the substrate. In the case of a spherical system under pressure, the mode keeps the same hexagonal shape as without substrate, but the post-buckling behavior tends also to become supercritical for a stiff core. Roughly the mode shapes remain often the same with and without substrate, but the post-buckling response becomes generally stable with a stiff substrate, what was almost never observed with pure shell structures.

A0650- Non-sinusoidal buckling patterns turned by micro-structure of film/substrate system

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The geometry of the micro-structure on the soft substrate, which is recognized by an array of micro-columns, can significantly influence buckling patterns and buckling load of stiff film/soft substrate system. When the column is relatively thin, non-sinusoidal buckling patterns will appear. With finite element eigenvalue analysis, the column is found to participate in bending or tensile deformation. The result can be explained qualitatively by the change of energy distribution between film and substrate with micro-structure, which is different from the traditional film/substrate system with perfect interface. Whatever the geometry of micro-structure is, there will exist quasi-sinusoidal buckling pattern, which is called upward-buckling. In the past research, the buckling of non-contact film is simplified as the Euler buckling of the ends-clamped beams. It is found that this simplification only applies to the situation when the column is quite thin. As the width of the column increases, it will cause significant errors. Therefore, we model the film as a beam elastically restrained against rotation whose extreme case is ends-clamped beam or ends-fixed beam. With the help of numeral calculations, the elastic rotational stiffness applied to the beam can be obtained. The elastic rotational stiffness can be used as a measure of the constraint effect of column on the non-contact film, which is closely related to the geometry of micro-patterns and can guide the prediction of buckling load.

A0715- Electromechanical catastrophe

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A transducer is a system that couples two loads. For a membrane of dielectric elastomer sandwiched between two compliant electrodes, it couples a mechanical force and an electrical voltage. Attributes of a dielectric elastomer transducer include large deformation, high energy density, low cost and fast response. Applications include actuators, generators and sensors. Such a two-load, nonlinear system can exhibit rich behavior of bifurcation, which can be displayed in a three-dimensional space, with the two loads forming the horizontal plane and a state variable forming the vertical axis. In this three-dimensional space, a state of equilibrium of the system under fixed loads corresponds to a point on the surface, called the behavior surface. The surface is smooth, but the singularity theory proves that the projection of the behavior surfaces to the load plane results in singularity of two types: fold and cusp. Here we identify the fold and cusp for a dielectric elastomer transducer by a combination of theory and experiment. We construct a three-dimensional space, with one axis being the stretch, and the other two axes being the electrical and mechanical loads, and then we project the surface onto the voltage-stretch plane, force-stretch plane and the force-voltage plane. We conduct two kinds of experiments: electrical actuation under a constant force and mechanical pulling under a constant voltage. Good agreement between the theory and the experiment is obtained both on the deformation history and the determination of folds and cusp. The fold and cusp are essential in the design of loading paths to avoid or harness the bifurcation.

A0844- Analysis and prediction of uneven settlement due to a curved shield metro tunnel

Surface settlement is a natural phenomenon of ground disturbance in subway tunnel construction. Dissymmetrical surface settlement profiles are observed when shielding in a curved tunnel, but these observations are quite different from the predictions of typical formulae which indicate a symmetrical surface settlement profile in straight tunnels.

Based on the field measurements from shielding subway tunnels in soft ground located in Southeast Asia, the relation of the uneven distribution of jacking thrust and the mechanics of dissymmetrical settlement are discussed, and the method of calculating the dissymmetrical settlement profile is proposed in this study. The methods proposed in this article can be used to properly predict the surface settlement induced by a single curved tunnel in similar geological and construction conditions. The results also provide a reference set of shield construction parameters.

MS4: Computer Vision-based Studies in Structural Health Monitoring

A0372- System identification and seismic response monitoring of large-scale bridge models using target-tracking digital image correlation

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The objective of this presentation is to demonstrate the potential use of video monitoring techniques for bridge system identification, structural health monitoring, and seismic response evaluation for post-earthquake operation and/or repair decision making. The paper presents the results and discussion of target-tracking and digital image correlation (DIC) monitoring of two large-scale (about 1/3 scale) two-span bridges under bidirectional earthquake loading in the Earthquake Engineering Laboratory of University of Nevada, Reno. This study consists of two parts. The first part aims at validating and verifying response monitoring from DIC using data from conventional sensors, i.e. string displacement potentiometers and triaxial accelerometers. This part of the study also presents the comprehensive monitoring and comparison of the overall seismic response of the bridge systems and dynamic interaction at different levels of seismic excitation. The second part of this study focuses on the structural system identification of both bridges with the determination of structural model parameters based on DIC measured response data. Before and after each seismic test, low amplitude white noise base excitation tests were conducted and in turn, a quasi-linear response of the system was assumed to estimate the modal parameters of an equivalent linear time-invariant (LTI) model for each bridge system. Using the structural vibration data recorded by DIC and accelerometers, three system identification methods, including single-output-single input (SISO), single input-multiple output (SIMO) and two output-only (SSI-DATA) are used to estimate the modal identification, i.e. frequency, damping, and mode shapes of the bridges.

A0387- Automatic bolt loose detection based on digital image processing technology

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Bolt connection is an important connection form in bridges, buildings, pipelines, transmission towers, and other civil structures. The looseness of the connection node in structures often leads to the damage or even collapse of structural systems, hence the monitor and inspection of bolts connection in structures are very important. In general, loose bolts could be visually inspected by inspectors to assess health status. However, traditional visual inspections are time-consuming, cumbersome and inaccurate. With the development and maturity of image processing technology, image processing could be applied to loose bolt detection of large-scale structures, which is an automatic and rapid detected method to ensure the safety during detection process This paper proposes a method of automatic bolt looseness detection, all testing processes are automatically completed in one step, including preprocessing, edge recognition, image correction and angle calculation. In this study, we identified the rotation angle of the nut from the images, by the following steps: First, camera capture bolt photos. and then, the images were corrected by image processing techniques and bolt edges were extracted. Finally, determining the angle of each bolt and calculating the rotation angle. We verified the applicability of this method through a set of experiments. The results demonstrated that the measurement error of this method was less than 5.5%, which suggested that this method could accurately detect the looseness of bolts.

A0910- An algorithm for identification of structural parameters and excitation forces using noncontact vision-based displacement measurements

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The identification of structural parameters and external excitation forces is important for structural health monitoring (SHM). During the past two decades, although recent researches have demonstrated some maturity for vibration-based SHM, the requirement for installing dense point-wise sensor (e.g., accelerometers, strain gauges, LVDT, etc.) networks would take considerable measurement cost, time and effort, and traffic disruptions. Due to the recent advances in sensor technology and computational capability of computers, the use of vision-based approaches for condition assessment of structures offer a promising alternative opportunity to improve the resilience of structural systems. In contrast to the conventional extensively used point-wise sensors, displacements of a large number of points can be extracted by computer vision. One major essential task is to further advance the noncontact vision sensor technology for practical SHM applications, by validating the feasibility of the simultaneous identification of structural stiffness and external excitation forces utilizing low-cost vision-based displacement data. In this paper, the recent generalized extended Kalman filter, which recently has been proposed by the authors, is extended to investigate the real time simultaneous identification of both structural stiffness and external excitation forces utilizing vision-based displacement measurement identification of structural parameters and excitation forces using displacement measurements. A numerical example is investigated to evaluate the accuracy of the proposed algorithm. Effects of different noise levels, sensor numbers and initial estimates of structural parameters on the identified results are studied in detail. The proposed algorithm can be integrated with computer technology for efficient and low-cost periodic or long-term performance assessment of civil infrastructures for the resilience of structural systems.

MS5: Nonlinear Stochastic Structural Dynamics Methodologies for Complex Engineering Systems

A0659- An efficient stochastic complex modal analysis technique for nonclassically damped and nonlinear mdof structural systems

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A novel inelastic modal decomposition method for random vibration analysis in allingnment with contemporary aseismic code provisions (e.g., EC8) considering non-classically damped and nonlinear multi-degree-of-freedom (MDOF) systems is developed. Relying on statistical linearization and state-variable formulation the complex eigenvalue problem considering non-classically damped, nonlinear MDOF structural systems subject to a vector of stochastic seismic processes characterized by power spectra compatible in a stochastic sense with a given elastic response uniform hazard spectrum (UHS) of specified modal damping ratio, will be addressed. Equivalent modal properties (EMPs) of the linearized MDOF system, namely equivalent pseudo-undamped natural frequencies and equivalent modal damping ratios will be provided. To this aim, the system response covariance matrix needs to be estimated. Subsequently, the EMPs of the structure will be utilized together with the appropriate mean response elastic UHS for determining peak nonlinear responses. Note that a significant advantage of the technique relates to the involved decoupling and the derived EMPs which are not only able to capture the trend of the inelastic behavior, but they are also clearly amenable to a physical meaning.

A0802- A hybrid sem–sm method for subway random dynamic loads induced by the frequency-dependent dynamic properties of rail pads

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For an effective and accurate prediction of the main excitation source of subway environment vibrations and wheel–rail noise (i.e., the random dynamic loads of subway vehicles), according to the periodicity of rail–fastener system and high-frequency elastic wave characteristics of rail, a hybrid SEM–SM method is proposed. Based on the measurement of the frequency-dependent dynamic properties of DT III rail pads frequently used in China's subway, the hybrid SEM–SM method was used to investigate the influence of the frequency-dependent dynamic properties of DT III rail pads on subway random dynamic loads. There are four main conclusions. (1) The storage stiffness of DT III rail pad within 0.1–10000 Hz at 20°C have an approximate linear relation with frequency in a logarithmic coordinate system, while the loss factors of DT III rail pad firstly increase and then decrease in frequency domain. (2) The frequency-dependent dynamic properties of rail pads can increase the subway random dynamic loads in two dominant frequency domains, 32–80 Hz and 500–1250 Hz respectively. Thus, the frequency-dependent dynamic properties of rail pads should be considered in prediction of subway environmental vibration and wheel–rail noise. (3) The influence of the frequency-dependent dynamic properties of rail pads on subway random loads is equivalent to the effect of the vehicle speed increase of 92 km/h, while the influence of the shortwave track irregularity on subway environment vibrations is less than the effect of the frequency-dependent dynamic properties of rail pads unless there is a pretty serious shortwave track irregularity. (4) The proposed hybrid SEM–SM method in which only one element is required to compute the high-order vibration modes of infinite rail is appropriate for high-efficiency analysis of subway random dynamic loads in high frequencies.

A0890- Stochastic response analysis of an offshore wind turbine under the excitations represented by stochastic harmonic function

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Simulation of the wind and wave loads acting on an offshore wind turbine is one of the most critical tasks in its structural design and reliability assessment. The spectral representation method (SRM) is the most widely used method at present, which, however, involves a large number of random variables and results in much cumbersomeness in the reliability analysis of the system. To reduce the random variables in the simulation of fluctuating wind speed fields, the stochastic harmonic function (SHF) representation was developed recently based on a wavenumber-frequency joint spectrum. Compared to the SRM, in the SHF representation method both the phase angles and frequencies/wavenumbers are regarded as random variables. Along this line, the wave surface elevation is also simulated through the SHF representation in the present paper. Besides, the subdomains involved in the SHF representation are specified by the Voronoi cell partitioning scheme after determining the representative points by the acceptance-rejection method. In this way, the number of the random variables and the computational efforts are dramatically reduced simultaneously. For illustrative purpose, the stochastic dynamic response analysis of an offshore wind turbine is addressed, demonstrating the effectiveness of the proposed method.

MS6: Damage Modelling of Engineering Structures

A0169- Concurrent fatigue crack growth and vehicle-bridge dynamics analysis using time-based sybcycle formulation

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Bridge structures are prone to fatigue damages as they undergo traffic loading. The bridge responses under vehicle loading are usually complex due to the interaction between the vehicle and bridge. The classical cycle-based formulation for fatigue crack growth has intrinsic difficulties in dealing with these complex loading spectrums since they often cannot be described as cyclic. In this study, a time-based subcycle formulation for fatigue crack growth is introduced to address this difficulty. The proposed model includes three major components: 1) a time-based crack growth kinetics function at the subcycle scale; 2) an efficient crack tip opening displacement (CTOD) estimation method; 3) a crack tip plasticity zone tracking algorithms for crack opening level determination of a moving crack. For demonstration, a simply supported steel girder bridge is adopted. Numerical simulation is conducted using full-scale three-dimensional vehicle and bridge models. An initial crack is assumed to be located on the bottom flange of the steel girder and the crack growth is analyzed using the proposed method. A parametric study is conducted to investigate the effects of road surface condition, vehicle weight, vehicle speed, vehicle dynamics, and traffic volume on the crack growth rate.

A0406- Data normalization and damage detection framework for operational wind turbines in varying operational environments

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Wind turbines are complex engineered structured designed to convert wind energy into electrical energy. Their large size coupled with an extremely demanding load environment can lead to damage over the life-span of the wind turbine. Given their high costs and importance in providing electrical energy, there is growing interest in monitoring wind turbines and assessing their health using monitoring data. A major challenge associated with structural health monitoring (SHM) of wind turbines is the varying nature of their environmental and operational conditions (EOC). This work explores an approach to extracting EOC data from the measured structural response of wind turbines. A data normalization process is performed by clustering EOC features measured using a Gaussian mixture model. With the EOC space delineated by clustering, data from an operational turbine in an unknown state is assigned by EOC features to a cluster. Damage-sensitive features also extracted from monitoring data is then compared to the baseline healthy state of the structure for a given EOC cluster to hypothesize the condition of the structure. This framework is validated using a small 5 kW wind turbine located in Los Alamos, New Mexico. A wireless monitoring system is installed on the turbine to measure the lateral vibration of the turbine tower. The acceleration data collected is used to assess the condition of the structure. A controlled damage state is introduced in the form of a soft spring introduced at the turbine foundation. The study finds the methods presented are effective in classifying the health of the structure.

A0451- Simulating time-dependent quasi-brittle failures based on a multilinear releasing mechanism of viscous force fields

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The time-dependent progressive failure processes in heterogeneous brittle materials are modeled by considering the temporal stress redistribution mechanism due to local breakages. The influence of local breakages lies in two successive kinds of stress redistributions: (1) Internal forces in the breaking element is assumed to release infinitely fast when compared with external loadings, while the specimen takes time to deform correspondingly due to material viscosity. This deformation delay is implemented by introducing a viscous force (VF) field all over the specimen. (2) The second is the gradual release of VF fields stored previously which is approximated as a multilinear process. The algorithm only includes linear computations and is free of nonlinear iterations. Numerical results of uniaxial tensile/compressive, anchor bolt pull-out and Brazilian tests show that the proposed model is capable of overcoming the over- brittle issue in existing lattice models and capturing the strain rate sensitivity, which agree well with experimental observations.

A0477- Machine learning based multiscale modeling of backward erosion piping

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The presented research provides a novel multiscale modeling framework to simulate the evolution of Backward Erosion Piping (BEP) processes in Flood Protection Systems (FPSs). Numerical simulations are performed at the local scale by means of a multiphase description, and results are used as the training set for a multi-layer Machine Learning (ML) algorithm to bridge the information between scales. The capability of generating results in a fast, yet accurate manner is exploited in the parametric study of the proposed physical model. Accuracy of the so trained ML algorithm is demonstrated by comparing results obtained from detailed numerical models. The multiscale approach is also employed in the construction of response tables, which present results in a convenient graphical fashion. The goal of this study is to allow for real-time predictions of the overall response at the system scale level. A case study is presented where the entire portion of the Nashville Metro Levee System is studied in a span of a year, to assess the likelihood of BEP to undermine its stability.

A0651- Analysis of seismic collapse of high-rise structure under near-fault pulse-type ground motion

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The near-fault pulse-type ground motions has great potential damage ability to the high-rise structure, which will increase the risk of seismic collapse of structures. In this study, incremental dynamic analysis method combined with material damage model was used to quantitatively analyze the seismic collapse of a high-rise building subjected to near-fault pulse-type ground motions. In particular, the paper focuses on the analysis of the relationship between the P-delte effect and the related energy changes, which. are closely related to the structural collapse.

A0827- Scaling effects for dynamic responses with application to buried arches subjected to internal blast

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Earth covered arch structures provide an economical solution for storing ammunition and other explosive materials. To assess the blast resistance of the storage structure, experimental study is always necessary, because any analytical or numerical models require verification based on experimental results. As compared to full-scale experiments, scaled down model test is a much cheaper and easier alternative. So far, most of the scaled model experiments are conducted using replica scaling method, in which the models are geometrically scaled from the prototype while keeping the material properties unchanged. However, three common phenomena, namely strain rate effect, concrete fracture and gravity, violate the replica scaling law, and hence they may potentially diminish the accuracy of the scaling results.

This research is carried out to first evaluate the effect of each non-scaling phenomenon in the blast loaded buried arches, and then, for the more prominent sources of scaling distortions, to propose new scaling methods to reduce the scaling errors. Numerical simulations show that the strain rate effect and concrete fracture are the two major scaling distortions, whereas the scaling errors due to gravity effect is insignificant. Therefore, new scaling methods are required to reduce the scaling errors due to strain rate effect and concrete fracture.

A new set of scaling law, the strain rate scaling, is developed to reduce the scaling errors due to the strain rate effect in steel material. Numerical simulations are performed on blast loaded buried steel arches to prove the superior scaling performance of the strain rate scaling over the classical replica scaling. The strain rate scaling method is also applicable to other dynamically loaded steel structures, and the wide applicability of the new scaling law is demonstrated through numerical simulations. A series of model and prototype drop-weight impact experiments are performed to illustrate the application process and to further validate the strain rate scaling law. The strain rate scaling law is also extended to situations where the model and the prototype are built from different steel grades.

A0879- Constitutive modeling of ductile and brittle failures of semicrystalline polymers

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Semicrystalline polymers, such as high density polyethylene (HDPE), have become increasingly popular in infrastructure applications due to their low cost and high strength-to-weight ratio. However, many of these engineering applications involve corrosive environments, which cause material embrittlement and eventually catastrophic structural failures. This study aims to develop a constitutive model to capture the transition between the ductile and brittle failures of HDPE based on the molecular weight and crystallinity. An elaso-viscoplastic model is used to capture the ductile behavior due to the intermolecular resistance of the crystalline and amorphous phases, as well as the entangled network resistance of the amorphous phase. The contributions from the individual phases to the overall load resistance is governed by the polymer crystallinity. These plastic deformation mechanisms lead to network disentanglement, crystal breakdown, and initiation of micro-voids. The void growth in the crystalline and the amorphous phase causes the ductile failure of the polymer. When the maximum principal stress in the amorphous phase reaches a critical value, micro-voids would localize into crazes, and the growth and breakdown of these crazes cause crack propagation signifying a brittle failure mode. To capture this transition of the failure mechanism, a continuum model of crazing damage is combined with the elasto-viscoplastic model. The model parameters are explicitly related to the molecular weight of the HDPE, and its dependence is calibrated by using the uniaxial tensile tests at various deformation rates, crystallinities, and corrosion levels. The constitutive model is validated by the finite element simulations of double edge notch tests for different corrosion levels. It is shown that the model can capture well the time-dependent stress-strain behavior and predict the transition between the ductile and brittle failure modes of HDPE in a corrosive environment.

MS7: Non-Deterministic Modelling and Uncertainty Management in Structural Dynamics and Vibroacoustics

A0044- Structural reliability and reliability sensitivity analysis of extremely rare failure events by combining sampling and surrogate model methods

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The aim of this paper is to study the reliability analysis, the parametric reliability sensitivity (PRS) analysis and the global reliability sensitivity (GRS) analysis of structures with extremely rare failure events. Firstly, the GRS indices are restudied, and we show that the total effect index can also be interpreted as the effect of randomly copying each individual input variable on the failure surface. Secondly, a new method, denoted as AK-MCMC, is developed for adaptively approximating the failure surface with the active learning Kriging surrogate model as well as the dynamically updated Monte Carlo (MC) or Markov Chain Monte Carlo (MCMC) populations. Thirdly, the AK-MCMC procedure combined with the quasi-optimal importance sampling (IS) procedure is extended for estimating the failure probability, the PRS and GRS indices. For estimating the GRS indices, two new IS estimators are derived. The AK-MCMC procedure can be regarded as a combination of the classical AK-MCS and subset simulation (SS) procedures, but it is much more effective when applied to extremely rare failure events. Results of test examples show that the proposed method can accurately and robustly estimate the extremely small failure probability (e.g., 1e-9) as well as the related PRS and GRS indices with several dozens of function calls.

A0079- Model-form and parameter uncertainty quantification in structural vibration simulation using fractional derivatives

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Extensive research has been devoted to engineering analysis in the presence of only parameter uncertainty. However, in modeling process, model-form uncertainty arises inevitably due to the lack of information and knowledge, as well as assumptions and simplifications made in the models. It is undoubted that model-form uncertainty cannot be ignored. To better quantify model-form uncertainty in vibration systems with multiple degrees of freedom, in this paper, fractional derivatives as model-form hyperparameters are introduced. Two types of hyperparameters for damping and elasticity force are differentiated. A new general model calibration approach is proposed to separate and reduce model-form and parameter uncertainty based on multiple fractional frequency response functions. The new calibration method is verified through a simulated system with two degrees of freedom. The studies demonstrate that the new model-form and parameter uncertainty quantification method is robust.

A0129- Dynamic response of a train-bridge intraction system due to sudden deceleration in high speed railway systems

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This study is intended to investigate dynamic responses of a train-bridge interaction system with a sudden deceleration utilizing the commercial finite element software ABAQUS as an emergency brake of train is a crucial technical issue in high speed railway system. Few studies have investigated dynamic responses of train-bridge interaction system with a series of deceleration train cars. Therefore, this study also examines the influence of emergency brake of a series of train cars on the bridge strucure. A typical Shinkansen system—Japanese high-speed railway, which consists of 16 cars and a 3-block bridge is the target railway system to be investigated. The car comprises car bodies, bogies and wheelsets, which are all modelled by rigid bodies and connected with springs and dampers. The bridge is modeled with solid elements. As for the interaction, a penalty friction method is applied to simulate the extreme locking brake case when sliding happens between wheels and tracks. This model was compared with a general deceleration model. The emergency brake showed considerable effects on longitudinal acceleration of train vehicles and vertical dynamic responses on pre-specified points of the bridge. It is noteworthy that observations from this study can provide reference information of impact factors and riding comfort of train for design codes. Moreover, the proposed numerical approach encourages to extend the application to investigation of train and bridge responses in extreme situations such as derailment.

A0145- A robust approach to quantifying forecasting uncertainty using proxy simulations

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When using numerical models, analysts are often confronted with the situation whereby simulation predictions are used to inform decision-making in a domain where experimental data are unavailable. In such cases, the numerical model is trusted to predict in the application domain simply because it has been shown to be trustworthy in the validation domain, where experimental data are available. The difference between application and validation domains, however, can often result in significant extrapolation of the model that reduces confidence in predictions in the application domain, for example, when a model validated against linear vibration data is used to predict in-service performance when a nonlinear response is induced. The challenge of predicting in the application domain is further exacerbated due to the fact that calibration can result in parameter uncertainty induced by (i) model form error, which is the inability of the numerical model to exactly replicate physics, and (ii) lack of model distinguishability, which occurs when different sets of parameter values are able to replicate the experiments. For these reasons, calibration results in parameter values that reflect a best fit to experimental data rather than converging to their "true" values. Thus, calibration introduces compensating effects to parameter values that must be accounted for when predicting in either the validation or application domains.

Although the inherent dangers of prediction extrapolation are widely recognized, few methods are available to actually establish its credibility for a given application. It is our contention that numerical predictions should be as robust as possible to sources of uncertainty when predicting in the application domain. Herein, we propose an approach to calibration that utilizes info-gap decision theory to provide a measure of robustness to the

combined effects of extrapolation and compensating errors. Rather than searching for parameter values that best-fit experimental data in the validation domain, our methodology is to search for parameter values that are robust in both the validation and application domains. Satisfying boundaries, which are isocontours of the parameter values that produce fidelity-equivalent solutions in the parameter space, can be compared in both the calibration domain and the application domain to formulate a robustness indicator. Doing so can inform the degree to which calibration errors can be tolerated while still ensuring a critical level of forecasting robustness. The basic premise is that robustness to the effects of compensating errors and extrapolation can be quantified using prediction variability when parameter values are allowed to vary away from their calibrated settings. Robust calibration is performed considering the ability to replicate experimental data in the validation domain, and proxy simulations representative of the application domain. Our methodology is demonstrated using a simplified structure. Our approach highlights the fact that, confidence in model predictions in the application domain is increased when predictions remain as robust as possible given the unavoidable sources of uncertainty in the numerical model.

A0323- Modeling the asymmetric dependant soil variables

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Multivariate information of soil parameters is quite important for the design and risk assessment of geotechnical engineering problems. It is necessary to have an accurate and realistic statistical multivariate model for representing the soil properties and thus evaluating the soil conditions. Thus, advanced multivariate modeling of soil parameters could help to improve the geotechnical engineering practice. In this paper, the asymmetric copulas are introduced to model the geotechnical soil data. Compared to extensive previous research on the use of symmetric copulas on the modeling of engineering data, this study is focusing on capturing asymmetric dependencies among the natural soil parameters, which are critical to engineering designs. A copula-based multivariate probabilistic model is built based on a set of collected samples from a granite residual soil from Portugal. Several asymmetric copula functions, capable of capturing nonlinear asymmetric dependence structures, are tested and analyzed. The fundamental information on tail dependencies and measures of asymmetric dependencies are also exploited. To demonstrate the advantages of asymmetric copulas, the asymmetric copula concept is compared with the traditional copula approaches for modeling site soil data. The performance of these asymmetric copulas is discussed and compared based on data fitting and extreme value characterizations.

A0414- Non-probabilistic model of transmissibility functions based on complex ratio interval arithmetic

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Due to its clear physical interpretation in characterizing the dynamics of a system, transmissibility functions play important roles in many related fields such as structural damage detection and modal analysis. Uncertainty quantification for transmissibility functions is of practical importance in improving the robustness of their real applications. Interval analysis has been a popular mathematical tool to deal with the uncertainties of engineering problems in which only the lower and upper bounds of uncertain parameters are required. Determining the bounds for an interval could be easier and more straightforward than the identification of probability distributions. Therefore, interval analysis is appealing for the cases when probability information is missing. Defined as the ratios of two complex-valued random variables, transmissibility functions are complex ratio random variables. Direct use of the arithmetic operation rules of interval analysis to compute complex interval division can lead to significant interval expansion, which hinders its real applications significantly. In this paper, we propose an efficient algorithm to address the issues aforementioned. The reciprocal of the denominator is computed with maximum accuracy by mapping complex interval into a region bounded by four circular arcs. As a result, the interval of transmissibility functions can be achieved by multiplying a smallest rectangular region containing the above region with the numerator. Monte Carlo simulation (MCS) is used to verify the proposed scheme. Furthermore, a number of samples of transmissibility functions obtained from field test data of a bridge is used to verify the accuracy and efficiency of the algorithm. Results indicate that, by comparing with the subinterval method, the algorithm is able to efficiently suppress interval expansion. Therefore, the proposed methodology can be used to quantify the uncertainty of transmissibility functions effectively.

A0439- The bhattacharyya distance: a novel uncertainty quantification metric in stochastic sensitivity analysis

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It has been widely accepted that uncertainties should be appropriately considered in the campaign of verification and validation (V&V) for computational models. Uncertainty quantification (UQ) metrics are consequently significant with the expectation to provide an elaborate measurement of the uncertainty information. By providing an absolute geometry distance between two single points, the Euclidian distance is probably the most common metric especially in deterministic model updating and sensitivity analysis approaches. Alternatively, the Bhattacharyya distance is a stochastic metric between two samples considering their probabilistic distributions. The Bhattacharyya distance is clearly more comprehensive for uncertainty treatment, however, its application in V&V is quite limited in the current literatures. This is not only caused by a huge calculation burden but also, more critically, caused by its stochastic character when evaluating the distance between two random samples.

Sensitivity analysis is a key component of V&V, generally performed prior to model updating, with the purpose to evaluate and rank the significance of each parameter according to the quantity of interest (QoI). Too many investigating parameters leads to a huge calculation cost, and even renders the updating of true significant parameters intractable. Consequently, the objective of this work is a stochastic sensitivity analysis approach in which the Bhattacharyya distance is perfectly embedded as UQ metric. Since the model updating process can be deterministic or stochastic, the investigating parameters and QoI vary among various applications. In this work, not only the parameters themselves, but also their uncertainty characteristics, e.g. mean and variance, are investigated with the help of the novel UQ metric. Statistical techniques such as analysis of variance and design of experiments are involved in the framework so that the significance factors of the uncertain parameters are evaluated. Feasibility of the novel UQ metric in association with the stochastic sensitivity analysis is demonstrated in simulation examples.

A0459- Modal identification of structural dynamics using sparse representation under underdetermined condition

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Traditional blind source separation approaches can only handle determined or overdetermined blind problems for operational modal identification, where the number of observed signals is equal to or greater than active modes. When the number of observed signals is less than active modes, new methods to undertake the underdetermined blind conditions should be considered. This paper proposes a new modal identification method based on an improved sparse component analysis (SCA) to deal with the underdetermined blind source separation problem. Firstly, an improved K-means clustering algorithm with differential evolution algorithm is introduced to estimate mixing matrix (modal shapes matrix) using sparse characteristics of observed mixture signals. Having estimated mixing matrix, the modal responses are recovered via the smoothed zero-norm (SL-0) sparse recovery algorithm from the incomplete knowledge of the modal shapes matrix and the system output responses in time and frequency domain. Then, the modal responses are converted into time domain by inverse short Fourier transform. And the modal frequencies and damping ratios can be obtained by identification technique of single degree-of-freedom (DOF). Finally, a numerical simulation on discrete five DOF system shows that whether in determined or underdetermined conditions, the proposed method can perform accurate and robust parameters identification of structural dynamics.

A0508- An approach for robust model updating under uncertainty

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Increasingly attention has been poured into uncertainty of model in recent research. However, there is still some lack of knowledge about robustness of model updating solution. Considering uncertainty attribute to fluctuation of design variables and non-design variables, an approach for robust model updating is proposed in this paper to find a robust model updating solution. In this paper, robustness of the model is defined as the variance of the model analytical result under uncertainty. And in this method, model updating is constructed as a multi-objective optimization problem: the first objective is the accuracy of the numerical model and the second objective is the robustness of the model. NSGA-II algorithm is applied to solve this multi-objective optimization problem. Moreover, meta model based on moving least square method is established to reduce the computation. Two numerical examples are also employed to illustrate the efficiency of the robust model updating method, and the comparisons between robustness model updating solution and traditional model updating solution under different uncertain conditions are manifested in this paper.

A0535- A bayesian method for joint parameter optimal estimation based on power spectral density

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In this paper, A Bayesian method for joint parameter optimal estimation based on power spectral density is proposed and successfully applied to two typical kinds of identification of joint uncertain parameters. As well known, it's difficult to identify the uncertain parameters accurately based on finite measured response data since the existence of measurement noise and model uncertainty. Taken the displacement power spectral density (PSD) as the measured output, by introducing the Bayesian probability method, the formulation of the conditional probability density function for joint parameters under measured conditions is established. And the optimal estimation for joint parameters can be obtained via the Bayesian maximum posterior estimate. The proposed method exhibits excellent estimation performance and sound robustness.

A0801- Joint-stiffness identification of truss bridges using an enhanced water cycle optimization algorithm

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The prior knowledge on mathematical model governing to frame structures has a significant effect on structural identification results. In addition, the dynamic behavior of frame structures is directly related to the joint rigidities and accurate identification of the stiffness of structural joints plays an underlying role in achieving the reliable outcomes in structural condition assessment. This paper presents a robust strategy for joint-stiffness identification of truss bridges in time-domain using an enhanced water cycle optimization algorithm. In that regard, a constitutive formulation is developed for mathematical model governing semi-rigid connections in truss bridges. In the model, the structural connections between frames are modeled by xx (a sentence to explain the joint model you used.)Then, the recently developed water cycle algorithm (WCA) is modified to be applicable for joint-stiffness identification of such structures in time-domain. For this purpose, an efficient search space reduction technique is adopted through the optimization approach to enhance the global search capability of WCA. An experimental validation study is carried out on a laboratory scaled truss bridge. For comparison purpose, the appropriateness of the WCA in joint-stiffness identification is thoroughly compared with another state-of-the-art optimization algorithm i.e., particle swarm optimization (PSO). It is concluded that, the computational efficiency of the proposed strategy is significantly higher than that of PSO in dealing with rough initial estimates on structural parameters. This demonstrates the superiority of WCA strategy to handle global search over large design space with large number of design variables. It is also deduced that the proposed strategy could be successfully and confidently implemented for damage detection in structural joints with simultaneous identification of structural parameters. Finally, this research work was financially supported by National Science Foundation of China NAFC's research fund for International Young Scientist; Grant No. 51750110509 and the authors greatly acknowledge this financial support.

A0923- Dynamic response analysis of structures with hybrid random and interval uncertaities

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A novel dynamic analysis of structure with hybrid uncertainties (DASHU) is developed for the expressions for the lower and upper bounds of the mean value and standard deviation of the dynamic response. Within this approach, interval variables are adopted to quantify the non-probabilistic uncertainty associated with objective limited information. Some other parameters are considered as random variables. Based on series expansion of random and interval quantities with respect to uncertain parameters, by means of random interval moment method and perturbation technique, the proposed method evaluate the lower and upper bounds, the midpoint, and interval width of the first- and second-order moments of the structure response through solving deterministic equations. Monte-Carlo simulations method (MCSM) are implemented to validate the computational results. Finally, Numerical examples are analyzed to illustrate the feasibility and effectiveness of the proposed method. The influence on the structure response caused by the individual system parameters are also investigated.

MS8: Computational Modeling of Damage and Failure in Solids and Structures

A0392- Mitigating mesh dependence of stochastic computation of quasibrittle fracture

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Failure and damage of quasibrittle structures are often accompanied by various localization phenomena, which give rise to spurious mesh dependence of finite element (FE) simulations. Though extensive efforts have been devoted to developing computational approaches for suppressing the mesh dependence issue, the existing efforts largely focused on deterministic analysis. This paper will discuss the mesh dependence issue in stochastic computation of quasibrittle fracture. I will first present a new probabilistic crack band model, which is anchored by a probabilistic treatment of damage initiation, localization, and propagation. This model regularizes the energy dissipation of a single material element for the transition between damage initiation and localization. Meanwhile, the model also takes into account the random onset of damage localization inside the finite element for the case where the element size is larger than the crack band width. The random location of the localization band is related to the random material strength, whose statistics is described by a finite weakest-link model. The second part of the talk will discuss the extension of the model to dynamic loading. To this end, a rate-dependent finite weakest-link model is developed to capture the combined rate and size effects on the strength distribution of material elements. This model is validated by a set of stochastic discrete element simulations of aluminum nitride as a model system. The present results demonstrate that the rate-dependent finite weakest-link model can provide an analytical link between the discrete element simulation and continuum FE simulation, which leads to a promising multiscale stochastic computational framework for quasibrittle fracture.

A0633- Phase-filed modeling of hydraulic fracturing in the framework of the theory of porous media

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Hydraulic fracturing is a widely-used technique in the exploitation of oil and gas resources. Modeling the procedure needs to deal with the dynamic fracturing in porous media which is of interest to a broader community including engineering geology. To address the two challenging issues arisen from the cracking process and the multi-component aggregate, a systematic method is presented in the framework of the Theory of Porous Media (TPM) with the phase-field model embedded to handle the crack initialization and propagation. The TPM offers each constituent of the porous medium with an individual motion function and hence individual set of balance equation, and describes the coupling, i.e., the transfer of mass, momentum and energy between the individual components, using the so-called production terms. This feature when combined with the phase-field approach allows for the transition of the Darcy-type flow in the saturated porous media domain towards the Navier-Stokes-type flow in fractured zones. To further consider pre-existing closed fractures or fractures closing after generation, where either only the Darcy-type flow occurs or where the Navier-Stokes-type flow turns back to the Darcy-type flow, a crack-opening indicator is proposed to resolve the conflict between the two-way flow transition process and the monotonic evolution of the phase-field variable. The established method is then demonstrated by numerical results of 2-D and 3-D examples. The numerical results have also been compared with experimental observations in the literature where good agreement is found.

A0757- Cracking elements method for simulating multiple cracks

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The Cracking Elements Method (CEM) is a recently proposed novel approach for numerically simulating quasi-brittle fracture. CE is built in the framework of Finite Element Method (FEM), which does not need remeshing, cover algorism, nodal enrichment or any specific crack tracking strategies. The method is inspired by the statically optimal symmetric formulation of the strong discontinuity embedded approach (SDA-SOS) and use the standard Galerkin method, greatly reducing the coding effort. In CE, the crack paths are represented by disconnected cracking segments inside the cracked elements. No explicit or implicit descriptions of the crack's topology are needed, making the cracks as the solutions of the considered problems but not parts of it. Comparisons of the CE's results and the results obtained by some other methods such as XFEM indicate the effectiveness and robustness of the CE methods, which is capable of simulating multiple complex fracture patterns and cracks.

A0811- Stochastic analysis of polymer composites ruptures at large deformations modeled by a phase field method

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Carbon black reinforced natural rubber is a composite material that is increasingly being used in engineering applications. Detailed knowledge of the relationship between the composition of reinforced rubber and its fracture toughness is important for analysis and design of various engineering systems. To this end, the Arruda-Boyce model is adopted for modeling the hyper-elastic rubber matrix and a Neo-Hookean model is used for the reinforcing particles. A phase field method is then employed to simulate damage nucleation and propagation under quasi-static loading. The phase field hyper-elastic model is validated on a set of experimental data available in the literature. To quantify the uncertainty in the failure of these materials, a Monte Carlo simulation is carried out with random ellipsoidal particles distribution. Each realization undergoes large stretching up to failure, where force displacement curves and fracture surface energies are recorded. Failure of a sample is defined as the point where the load drops to the 75% of the peak force. Numerical examples of stiff inclusions and voids are considered and the composite response is examined on an intact and pre-notched unit cells. A rigorous stochastic analysis reveals the statistical distributions corresponding to the rupture of polymer composites and provides insight into better design of these materials.

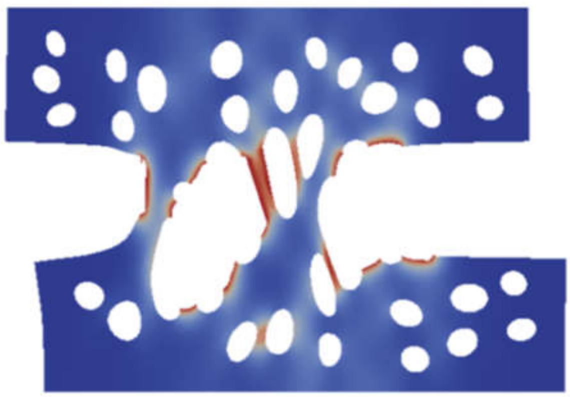

Figure1 Stretch and rupture of a polymer composite at large deformation

MS9: Reliability Analysis of Engineering Structures under Disastrous Excitations

A0022- A probabilistic analysis of a phenomenological model for structural collapse simulation

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The modified IMK model provides a powerful phenomenological model for collapse simulation of structures by reproducing nonlinear stiffness and strength degradation in the elements due to repeated cycles of loading. The accuracy of collapse simulation depends on realistic characterization of model parameters. Model parameters derived from experiments however have inherent uncertainties due to optimization. Collapse simulation based on deterministic parameter values of the modified IMK model might not provide reliable estimate of risk for collapse due to these parameter uncertainties. In this study, the modified IMK model is evaluated through probabilistically characterizing the model parameters based on three quasi-static cyclic tests of full-scale beam-column connections conducted previously at Lehigh University. The Metropolis-Hasting algorithm is utilized to derive the statistics of model parameters and compare with their deterministic values. Computational simulations are then conducted to evaluate the effect of mode uncertainty in terms of energy dissipation.

A0347- Simulation of stationary non-gaussian vector process within wave-passage effect based on spectral representation method

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Wave-passage effect is always of great importance when performing the dynamic analysis of lager scale structures. This effect can be easily considered in the simulation of Gaussian vector process, but there is not an efficient way to introduce it into the non-Gaussian vector process. In this paper, a method is proposed to generate stationary non-Gaussian vector process within wave-passage effect. In the simulation of vector process, wave-passage effect leads to a complex-defined cross spectral density matrix (CSDM). To separate the phase part from the CSDM, an improved form of spectral representation method (SRM) is proposed, in which the phase part representing the wave-passage effect can be directly expressed in an explicit form in the simulation formula. Then the characteristic of phase part representing the wave-passage effect during the nonlinear translation (translating underlying Gaussian vector process to the prescribed non-Gaussian vector process) is investigated. It is found that, the phase part is not changed. Based on this good feature, the modified SRM and the iterative scheme can be combined to simulate non-Gaussian vector process within wave-passage effect. Two examples, involving the simulation of seismic ground motions and wind velocity time histories, are presented to show the good feature as well as the characteristics of the simulated vector process.

A0349- Stochastic dynamic response analysis and reliability assessment of non-linear structures under fully non-stationary ground motions

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In this paper, stochastic dynamic response analysis and reliability assessment of nonlinear structures under fully non-stationary ground motions is investigated based on the probability density evolution method (PDEM). To handle this problem, a new method is proposed for points selection in high-dimensional random-variate space for PDEM, which is of paramount importance for the tradeoff of accuracy and efficiency. First, the original high-dimensional space is decomposed into several two-dimensional orthogonal subspaces. Then, each subspace is partitioned via the Voronoi cells and the representative points and assigned probabilities in each subspace are specified accordingly. Finally, the representative points and assigned probabilities in each subspace are randomly paired to formulate the representative points and assigned probabilities in high-dimension. Numerical example is studied to validate the proposed method, which indicates that the proposed method is of efficiency and accuracy for high-dimensional stochastic dynamic problem of structures. Problem needs to be further investigated is also pointed out.

A0403- Integrated reliability-based optimization of civil structure and vibration control systems using improved genetic algorithms

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Disastrous excitations such as severe earthquakes and strong winds pose a great threat to civil engineering structures. To improve the safety and serviceability of structures excited by external dynamic loads, significant efforts have been devoted to the investigations on structural vibration control. Various control strategies, including passive, active, semi-active and hybrid control systems, have been proposed and many control devices, like rubber bearings, buckling constraint supports, magnetorheological dampers and so on, have been developed and applied to civil structures. It has been proven that active / semi-active control effects are simultaneously related to input dynamic actions, control algorithms, the number and location of actuators / dampers and physical parameters of controlled structures. Therefore, it is necessary to conduct the optimization of the control system and the controlled structure as a whole. In this paper, an improved genetic algorithm is developed to solve reliability-based optimization problems for civil structure and active control systems, in which the number and position of actuators, the control algorithm, the structure parameter and the randomness of seismic excitations are taken into account synchronously. The optimization objective function is the failure probability of the controlled structure and the first excursion failure criterion is used in dynamic reliability analysis. Moreover, the reliability of the controlled structure is defined by inter-story drift angles and is performed using the theory of extreme value distribution and the probability density evolution method. In addition, a selection policy, which is a combination of random competition and elitist strategy, an improved binary single-point crossover and an improved single-locus or two-locus mutation are adopted in the developed genetic algorithm. Results of numerical examples conducted using MATLAB software show that the proposed algorithm has the advantages of high precision and fast convergence, thus it is an effective integrated optimization method for civil structure and vibration control systems.

A0520- Seismic fragility analysis of urban road network: a case study on tangshan city

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Recently, many studies have analyzed the vulnerability of the components of the roadway transportation system, such as embankment, cut, slope and road pavement, under earthquake attack. However, the seismic fragility analysis of the roadway network has not been fully investigated or applied in engineering practice. In this study, a framework for analyzing the seismic fragility of the urban roadway network is presented and used for the roadway transportation system in Tangshan City, China. This approach is based on the Monte-Carlo method. The spatial variation of the seismic ground motions is considered. By the proposed approach, the seismic performances of the roadway network under earthquake attacks of different intensity is presented and discussed. The present study shows that, for Tangshan City, the connectivity of the urban roadway network can be well maintained when the average peak ground acceleration (PGA) of the spatially variable seismic ground motions is less than 0.25g. The present work also advocates that when the PGA is larger than 0.55g the giant component of the roadway network is damaged and the roadway transportation system totally losses its functionality.

A0538- Impact of initial damage path and spectral shape on aftershock collapse fragility of RC frames

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The influences of initial damage paths and aftershock (AS) spectral shape on the assessment of AS collapse fragility are investigated. To do this, a four-story ductile reinforced concrete (RC) frame structure is employed as the study case. The far-field earthquake records recommended by FEMA P695 are used as AS ground motions. The AS incremental dynamic analyses are performed for the damaged structure. To examine the effect of initial damage paths, a total of six kinds of initial damage paths are adopted to simulate different initial damage states of the structure by pushover analysis and dynamic analysis. For the pushover-based initial damage paths, the structure is "pushed" using either uniform or triangle lateral load pattern to a specified damage state quantified by the maximum inter-story drift ratio. Among the dynamic initial damage paths, one single mainshock ground motion or a suite of mainshock ground motions are used in the incremental dynamic analyses to generate a specified initial damage state to the structure. The results show that the structure collapse capacity is reduced as the increase of initial damage, and the initial damage paths show a significant effect on the calculated collapse capacities of the damaged structure (especially at severe damage states). To account for the effect of AS spectral shape, the AS collapse fragility can be adjusted at different target values of ε by using the linear correlation model between the collapse capacity (in term of spectral intensity) and the AS ε values, and coefficients of this linear model is found to be associated with the initial damage states.

A0563- Structural reliability analysis using uqfem software

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In this talk, we will illustrate the usage of uqFEM, a software for driving uncertainty quantification in finite element and other analysis programs, with special emphasis on structural reliability applications. Recently developed by SimCenter (https://simcenter.designsafe-ci.org/) at University of California, Berkeley, uqFEM is an open source software tool that allows engineers to perform reliability-based computations for natural hazards and risk assessment. In the talk the usability and capabilities of the release version of uqFEM will be illustrated with numerical examples on benchmark structural reliability problems including tail distribution estimation. To conclude the talk, new features and uncertainty quantification algorithms planned for future releases will be discussed.

A0577- Seismic reliability analysis of energy-dissipation bridge structures using Hamiltonian Monte Carlo based subset simulation in conjunction with explicit time domain dimensionality reduction

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The seismic reliability analysis of energy-dissipation bridge structures is typically a local nonlinear problem, since energy dissipation devices are often installed in specific locations of a bridge structure. The Monte Carlo simulation (MCS) method has the applicability to solve generic non-linear reliability problems, yet the computational cost of MCS is often too high for engineering practice. The computational efficiency of using MCS to perform seismic reliability analysis is determined by the efficiency of the specific MCS scheme as well as the efficiency of a single run of deterministic nonlinear structural dynamic analysis. The paper proposes an efficient computational method for seismic reliability analysis of energy-dissipation bridges via the usage of: a) Hamilto-nian Monte Carlo based subset simulation to improve the sampling efficiency, and b) an explicit time domain dimensionality reduction technique to improve the efficiency of deterministic struc-tural dynamic analysis of local nonlinear problems. Numerical examples of bridge models are investigated to illustrate the efficiency of the proposed approach.

A0824- Assessing the spalling of tunnel linings subjected to fire loading

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Spalling is the violent splitting of concrete pieces from the fire-loaded surface, which greatly jeopardizes the integrity of the structures. Fires in tunnels commonly lead to a fast temperature increase during the first minutes of the fire with a maximum temperature over 1200 °C, potentially resulting into serious spalling. By developing and applying a fully coupled thermo-hydro-chemo-mechanical model, we firstly analyze the spalling of fire loaded plate-like structures. Then, we establish a fast assessing procedure for quickly evaluating spalling risk of tunnel linings with different concrete types and environmental moistures and propose criterion for grading the spalling risk. Comparisons between the obtained results and experimental results prove the effectiveness of our methods, which can be used by the engineers and designer for assessing the fire spalling risk of constructed and planed tunnel structures.

MS10: Damage and Fracture of Brittle and Quasi-Brittle Materials

A0034- Influence of asphalt mixture type on strength size effect statistics at low temperature

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Low temperature cracking represents a deleterious phenomenon for asphalt pavement experiencing cold climates. Hence, accurate evaluation of strength and fracture properties of asphalt mixtures is critical for ensuring the durability of the entire pavement structure. It was recently demonstrated that, at low temperature, asphalt mixtures behave as a quasi-brittle material and, consequently, its nominal strength strongly depends on structure size. In this paper, a comprehensive experimental study is conducted to evaluate the effect of mixture type on the scaling law for quasi-brittle strength. A standard asphalt mixture for wearing course and a Stone Mastic Asphalt (SMA) are selected for this purpose. Three-point bending tests are performed on unnotched asphalt mixture beams of four different sizes at low temperature. The strength values are evaluated based on the Weakest Link Model (WLM) in combination with the well-known Type I energetic-statistical size effect law (SEL). A significant variation in the evolution of the SEL is observed with a dramatic decrease in strength over size. The effect of mixture type indicates a significant influence on the statistics of strength with an increase of the grafting point in the cumulative distribution function of the representative volume element (RVE) for SMA. This is linked to an increased brittleness, which is overall compensated by the modified binder used for this specific mixture and by the higher material strength. The experimental and modeling results clearly demonstrate the importance of understanding the scaling evolution of asphalt mixture strength since this parameter is commonly used as input for pavement design purposes.

A0857- Modelling of damage and fracture of plain weave ceramic matrix composites under uni-aixal tension

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Ceramic matrix composites (CMCs) have the characters of low density, high modulus and good thermal stability. Over the past decades, great efforts have been made to study the mechanical behaviour of CMCs. Among them, Zhang and Hayhurst (2010) [Daxu Zhang, Hayhurst D R., 2010. Stress-strain and Fracture Behaviour of 0°/90° and Plain Weave Ceramic Matrix Composites from Tow Multi-axial Properties. International Journal of Solids and Structures. 47 (21). 2958-2969.] employed a homogenised finite element model to study stress-strain and fracture behaviour of cross-ply and woven CMCs. On the basis of this work, a non-linear multi-scale model has been developed to predict stress-strain response of plain weave CMCs under in-plane loading. A continuum damage state parameter determined by the ratio of failed fibres and total fibres was used to evaluate the longitudinal tensile behaviour of a unidirectional fibre-reinforced CMC tow. These analytical results of fibre tows were then employed by a finite element plain weave CMC unit cell model as the material properties, in which the tensile and shear properties of tows were nonlinear and were defined by a user defined subroutine in Abaqus. A Python script was developed to define the periodic boundary conditions of the unit cell. The uni-axial tensile stress-strain response has been predicted using the multi-scale model. The fidelity of the model has been verified by comparing its predictions with the experimental results.

A0863- Prediction of shear damage behaviour of fibre-reinforced ceramic matrix tows

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Ceramic matrix composites (CMCs) have the characters of low density, high modulus and good thermal stability. Over the past decades, great efforts have been made to study the mechanical behaviour of CMCs. However, a rigorous frame for understanding nonlinear shear behavior of CMCs on both microscopic and macroscopic level is lacking. Nevertheless, it is generally accepted that matrix cracking is the main damage mechanism which governs the shear stress-strain response of CMCs. In this paper, a model based on a single continuum damage state parameter determined by the ratio of the current matrix crack density and saturated density, has been developed to predict the shear behaviour of a unidirectional fibre-reinforced ceramic matrix composite (CMC) tow. The model considers the influence of matrix cracking using Weibull distributions of damaged matrix shear strength. The nonlinear shear stress-strain response of a CMC tow, predicted by the damage model, has been used in a macro-scale analysis to evaluate its fidelity.

A0866- Validation of the combined fem-dem on mode i and ii concrete rupture subjects to semi-circular bending

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To validate the effectiveness of the combined FEM-DEM under complex loading conditions, simulations are performed and results are compared with known semi-circular bending (SCB) tests based on concrete aggregate specimen with pre-existing notches. A bilinear strain-softening curve which is implemented into a cohesive fracture model is adopted to depict the behavior from continua to discontinua. A constant displacement rate is applied to the top center of the specimen. By comparing the simulation results from the FEM-DEM and the experimental data from known SCB tests, conclusions are reached that the combined FEM-DEM together with the cohesive fracture model can predict both Mode-I and II failure with good accuracy. For Mode-I fracture, a dominant flexural crack is obtained from the notch tip up to the loading point. On the other hand, an oblique crack is formed for Mode-II fracture, approximately linking the loading point and the notch. In general, the combined FEM-DEM is applicable of simulating Mode I and II fracture of concrete SCB specimen.

A0978- Impact fracture simulation of monolithic and laminated glass using hybrid discontinua and continua method

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This work presents a comparative study on the available numerical approaches for modelling the fracturing of brittle materials, e.g. glass and rock. These modelling techniques include four popular numerical methods such as the finite element method (FEM), extended finite element method (XFEM), discrete element method (DEM) and combined finite-discrete element method (FEM/DEM). This study investigates their inherent weaknesses and strengths for modelling the fracture and fragmentation process both in static and dynamic problem. A comparative review is first carried out to illustrate their fundamental principles as well as the advantages for the modelling of cracks, followed by state-of-the-art trial application in the example cases. Several examples of a glass beam subjected to low velocity impact are examined using aforementioned numerical methods as a plane stress problem. By evaluating their applicability, the most feasible model, i.e., FEM/DEM, for the entire dynamic fracture response is identified. It is further examined comparing with the experimental results for modelling the high speed and oblique impact tests on glass surface. Through such comparative study, the FEM/DEM exhibits the most satisfactory results when modelling the dynamic fracture of brittle materials with specific reference to glass. It also shows potential in simulating the composite action between ductile interlayer and brittle glass in the laminated glass. The Mooney-Rivlin model for the hyperelasticity of the PVB interlayers as well as the improved Xu and Needleman model serving as the mixed-mode interfacial constitutive law, in particular, describing the combined damage-plasticity behaviour for irreversible unloading are then implemented into FEMDEM. The impact damage of laminated glass in 2D problem including the interlaminar delamination and crack pattern is then examined by using such integrated approaches The comparison between the simulation and the experimental results for several laminated glass make-ups shows that this interfacial model can adequately reproduce the typical delamination behaviour. The characteristics of the stress wave propagation and the interlayer tearing in the example cases can be satisfactorily reproduced. The shortcoming of the discrete crack model in modelling the impact damage of strengthened glass and the resulting errors are discussed as well. Several potential solutions for such shortcomings are finally presented.

MS12: Dynamic Analysis and Seismic Performance of Structures under Strong Earthquake Ground Motions

A0008- Potential risks on using disconnected composite foundation systems in active seismic zones

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Choosing the suitable infrastructure system is becoming more challenging with the increase in demand for heavier structures contemporarily. This is the case where piled raft foundations have been widely used around the world to support heavy structures without extensive settlement. In the latter system, piles are rigidly connected to the raft, and most of the load goes to the soil layer on which the piles are bearing. In spite of that, when soil profiles contain thicker soft clay layers near the surface, or at relatively shallow depths, it is unfavourable to use the rigid piled raft foundation system. Consequently, the disconnected piled raft system was introduced as an alternative approach for the rigidly connected system. In this system, piles are disconnected from the raft using a cushion of soil, mostly of a granular interlayer. The cushion is used to redistribute the stresses among the piles and the subsoil. Piles are also used to stiffen the subsoil, and by this way reduce the settlement without being rigidly connected to the raft. However, the seismic loading effect on such disconnected foundation systems remains a problem, since the soil profiles may include thick clay layers which raise risks of amplification of the dynamic earthquake loads. In this paper, the effects of seismic behavior on the connected and disconnected piled raft systems are studied through a numerical model using Midas GTS NX Software. The study concerns the soil-structure interaction and the expected behavior of the systems. Advantages and Disadvantages of each foundation approach are studied and a comparison between the results are presented to show the effects of using disconnected piled raft systems in highly seismic zones. This was done by showing the excitation amplification in each of the foundation systems.

A0016- Output-only identification of civil engineering systems

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For mechanical systems and laboratory-scale structures, it is usually possible to arrange and carry out dynamic tests. Typically, the same is not possible for full-scale civil engineering systems (bridges, buildings, dams, tunnels, geotechnical arrays, etc.). As such, responses measured during natural events (earthquakes, hurricanes, etc.) provide the only means to examine structural responses in the most realistic manner possible. These examinations have multiple utilities, ranging from the development and validation of predictive models—including the characterization of uncertain loads—to health and performance monitoring. However, these naturally generated excitations are rarely measurable, rendering the requisite identification problems to be ill-posed for which both the system and the input excitations are unknown. For example, a building (or bridge) under its operational condition is usually persistently excited by ambient loads that are not measurable (like micro-tremors, ocean waves, people, car traffic, etc.). Or, it is not possible to record true seismic excitations to a building structure, because even the motions recorded at the foundation level are not purely input, due to inertial effects. Although various output-only system identification methods have been developed during the past few decades, they mostly adopt various simplifying assumptions regarding the statistical characteristics of the unknown input excitations—the primary assumption being the stationarity of the unknown input. Nevertheless, most real-life cases do not fall into this simplification, and thus the identified dynamic characteristics can have large errors. Over the past decade, the authors have been working towards the development of novel and robust output-only techniques to resolve deficiencies associated with these traditional output-only methods. In this paper, a comprehensive survey of their methods—ranging from model-free Blind Modal Identification (BMID) methods to model-based Bayesian filtering techniques—are presented, along with the application of these new techniques to real-life engineering problems.

A0024- Analysis of the bridge with single column by performance and reliability-based seismic design method

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The probability limit state design method based on reliability is one of the structural design's basic principles, A new generation structural seismic design must based on performance, it should consider the influence of random factors. Combining with the above two aspects, this paper studies the seismic reliability analysis method for the bridges with single column under different seismic fortification levels based on performance and reliability. The key points and flow chart of theoretical analysis methods of seismic reliability under different seismic fortification levels are described and given. Taking the bridges with single column as an example, the three-dimensional space model is established by Opensees platform. The pier and the whole bridge system's reliability are analyzed under different seismic inputs and performance levels by Probability Pushover Method (PPM). Compared with the values gained by using nonlinear Stochastic Finite Element Method (SFEM), the results show that the failure probability values gained by using nonlinear SFEM and PPM are basically identical, bridge system's failure probability is greater than a single component's failure probability under the action of earthquake. It can be widely used in bridge's seismic design.

A0105- Dimensional seismic responses of shear-flexural beam and self-similar interstory drift spectrum

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This paper investigates the influence of stiffness reduction along height on the seismic responses of shear-flexural beams subjected to near-fault ground motions by using dimensional analysis theory, and proposes a regression model for the self-similar interstory drift spectrum and self-similar floor acceleration spectrum. The stiffness along structural height is always nonuniformly distributed in realistic buildings, which is not sufficiently considered in the seismic response analysis of shear-flexural beams subjected to near-fault ground motions. This paper systematically analyzes the dimensional seismic responses of shear-flexural beams with nonuniform stiffness along height, wherein both analytical pulses and realistic ground motions are considered. The normalized responses are self-similar to the pulse amplitude and normalized structural height. It is shown that the self-similar interstory drift spectrum is affected by the lateral stiffness ratio of top to base end of shear-flexural beams. In contrast, the self-similar floor acceleration spectrum is almost not influenced by the lateral stiffness ratio of top to base end of shear-flexural beams. However, the effect of stiffness reduction is generally small and hence can be neglected in the preliminary design of buildings. A proposed regression model is suitable for the self-similar interstory drift spectrum and self-similar floor acceleration spectrum, which can predict maximum interstory drift ratio and maximum floor acceleration with acceptable accuracy.

A0109- A new approach to design explicit time integration algorithm with numerical dissipation

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The pseudodynamic testing and real-time hybrid testing in earthquake engineering require the fast and accurate dynamic analysis of structure. To develop the stable, accurate and efficient time integration algorithms is the important research topic. This paper proposes a family of explicit time integration algorithms for structural dynamics by utilizing the separate-design concept.

The traditional time integration algorithm uses the equation of motion and one set of recursive formula of velocity and displacement to solve the dynamic response of system. However, the new separate-design approach adopts two sets of recursive formula of velocity and displacement. One set of recursive formula of velocity and displacement is combined with and the motion equation to obtain the recursive formula of acceleration, and another set of recursive formula of velocity and displacement is utilized. As a result, the recursive formula of acceleration, displacement and velocity are achieved separately. The formulation coefficients of new algorithm adopt the structure-dependent parameters. The values or ranges of integration parameters are derived by making constraint conditions to meet the desired numerical properties. Further, the parameters are function of the spectral radius ρ, which controls the numerical damping. Theoretical analysis indicates that the new proposed explicit time integration algorithms possess the properties of second accuracy, self-starting, non-overshoot behavior for zero-order displacement and zero-order velocity response, unconditionally stable and controllable numerical damping. Moreover, the CR algorithm and KR-α method are special case of the new explicit algorithms. Finally, numerical examples demonstrate that the accuracy of new algorithms is superior to that of Generalized-α algorithms. The explicit time integration algorithms are applied to solve nonlinear dynamic responses of structures, which verifies the effectiveness and stability of the new algorithms.

A0112- Recent advances in engineering characteristics of near-fault ground motions and seismic effects of building structures

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Severe damages of civil infrastructures under near-fault ground motions have impelled the community of earthquake engineering to pay close attention and investigation to their engineering characteristics and structural seismic effects. This paper reviews the recent research advances of authors in the engineering characteristics of near-fault ground motions and seismic responses and base-isolated performance analysis of building structures. Firstly, two non-structure-specific intensity parameters, such as improved effective peak acceleration and velocity (IEPA, IEPV) were proposed. Two frequency content parameters were suggested, namely the mean period of Hilbert marginal spectrum T_{mh} and coefficient of variance of dominant instantaneous frequency of Hilbert spectrum H_{cov} which reflects the frequency nonstationary degree of ground motions. Meanwhile, a new stochastic model to synthesize near-fault impulsive ground motions with the feature of the strongest pulse was established. Then, the chaotic and fractal/multifractal characteristics of strong earthquake ground motions were analyzed deeply to explore their complexity from a novel perspective of nonlinear dynamics, and the inherent relation between fractal dimensions and period parameters of near-fault motions was exposed. Moreover, the mechanism of interstory deformation of tall building was illustrated based on the engineering properties of impulsive ground motions and generalized drift spectral analysis. Dimensional responses analysis of elastoplastic structures and self-similar response spectrum are presented. Finally, the influences of ground motion properties on the seismic responses and performance of tall structures and base-isolated buildings were revealed.

A0293- Optimal design of sma cable restrainers for seismic protection of a lrb isolated simply supported highway bridge

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Isolation bearings have been widely used to improve the seismic performance of highway bridges. Considering the flexibility of the isolation systems, isolated highway bridges are susceptible to unseating or even collapse due to excessive displacement under strong earthquakes. Shape memory alloy (SMA) wires with superior energy dissipation capacity and self-centering property can be utilized as seismic restrainers to limit the displacement. However, there is no appropriate design method for SMA restrainers in isolated highway bridges. The objective of this study is to evaluate the seismic performance of a LRB isolated simply supported bridge retrofitted with SMA restrainers. A design procedure for SMA restrainer is proposed according to a linearized two degree-of-freedom (DOF) analytical model. The optimal design parameters, i.e. the ratio of the allowable displacement to seat width (Δ_a/L_{sw}), normalized elongation parameter of SMA cables (α), and horizontal angle (θ_0) between the restrainer and horizontal level, are determined by conducting full factorial analysis. The results showed that the optimal values of the ratio of the allowable displacement to seat width (Δ_a/L_{sw}), which effectively reduces the relative displacement and simultaneously control the base shear of the piers, are between 0.4 and 0.7. The optimum value of the horizontal angle (θ_0) ranges from 0 to $\pi/4$. The optimum value of normalized elongation parameter (α) should be 1.0.

A0313- Features of offshore seismic ground motions distinct from the onshore

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The features of offshore ground motions have not yet been uncovered thoroughly for lacking seafloor measured data. This study managed to collect more than 1000 offshore and concurrent onshore site records from the K-NET and SEMS projects. These data are compared statistically in terms of the peak ground acceleration (PGA), the normalized response spectra of the horizontal and vertical components and the corresponding vertical-to-horizontal (V/H) ratios. The analysis indicates that in the same earthquake event and with identical epicenter distance, due to the effects of seafloor soft sediments and water layer, the offshore horizontal PGA is significantly amplified. Meanwhile, the PGA's V/H ratio of the offshore ground motions is much smaller than that of the onshore counterparts. For response spectra, the peak platforms of offshore ground motions lag behind the onshore records. Also, the offshore response spectra at long periods gain greater amplifications, which is critical to bottom fixed offshore structures. The V/H ratios of response spectra, offshore versus onshore, exhibit different trends varying with periods. Finally, to fill up the gap of current seismic design of offshore structures, a standardized response spectrum is suggested for the reference use in design codes.

A0355- Collapse performance assessment of self-centering precast concrete walls with different post-tensioning and energy dissipation designs

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Previous research have proved the excellent performance of self-centering precast concrete walls for use in seismic regions in terms of low damage and small residual deformation. However, these studies have mainly focused on evaluating the hysteretic behavior of the system through experimental testing and numerical simulation. This paper evaluates the influences of different designs of post-tensioning (PT) and energy dissipation (ED) components, which could be controlled by designers, on the collapse performance of self-centering precast concrete walls. The effects of different design selections for the response reduction factor (R) and collapse criterion are also examined. To this end, an example four-story self-centering precast wall building is designed and simulated using the numerical model that has been verified based on existed test data. A total of eight different designs are considered for the example building using various amount of PT and ED designs, and different R values. The established parametric models are analyzed to produce collapse fragility curves through incremental dynamic analysis using 44 ground motions. Based on results of collapse fragility data, collapse risk of all the parametric models are assessed according to the standard procedure in FEMA P695. The evaluation results show that ED designs have more influence than PT designs to the overall collapse fragility for self-centering precast walls. Nevertheless, all the prototype walls in the current study are demonstrated to have acceptably low probabilities of collapse, which meet the requirements in the design code.

A0523- Dynamic testing of a full-scale frp-retrofitted reinforced concrete building frame

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Many existing reinforced concrete buildings designed in accordance with pre-1971 codes are generally dominated by weak column-strong beam behavior under seismic loading due to inadequate reinforcement detailing. This behavior can lead to premature failure under seismic loads from damage concentrated in the first story of the structure. This paper presents full-scale dynamic testing of a non-ductile reinforced concrete frame retrofitted using a fiber-reinforced polymer jacketing system on the first story columns. This retrofit scheme was determined based on visible damage patterns and locations (e.g. flexural, shear and lap-splice failure on the first story columns) of an as-built test frame. The full-scale dynamic test was performed to investigate the dynamic performance of the retrofitted building structure in terms of the modal response, inter-story drift, and effectiveness of the fiber-reinforced polymer jacketing system. The results demonstrate that the retrofit scheme helped develop a more uniform story drift distribution, working to counter the soft-story mechanism commonly found in reinforced concrete frames designed during this period.

A0530- Simplified model based on spectrum analysis for the optimal outrigger location of high-rise buildings

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The outrigger system is a current alternative to reduce the dynamic response of high-rise buildings. The aim of the study is to develop analytical methods for earthquake response of a conventional outrigger system and to determine the optimal outrigger location. A theoretical simplified model is developed based on a dynamic time-history load and is further improved by mode-superposition response spectrum method. The model is then calibrated via an ANSYS model, and the simplified model is applied to perform parametric analyses to acquire the optimal outrigger location of each scheme. All data obtained from parametric analyses are summarised to solve the fitting equation of optimal outrigger location. Finally, a comparison of the results between time-history and spectra analysis suggest that the simplified model based on spectrum analysis effectively simulates the seismic behaviour of structure with an outrigger and its corresponding fitting equation reasonably expresses the optimal outrigger location of the aforementioned type of structure under seismic action. Additionally, the optimal outrigger location is first proposed in the form of an explicit equation that is conveniently used in the initial design process of a conventional outrigger.

A0567- Modeling and performance assessment of base-isolated buildings

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The behavior of high damping rubber bearings is highly complex. Existing models are generally unidirectional and for the most part difficult to extend to general bidirectional loading. One of the major limitations is their inability to characterize the behavior of the bearings at different levels of shear deformation. In the present work, a set of bidirectional models are proposed and implemented, obtained by simple combinations of well-known bi-dimensional formulations. The models are shown to accurately describe the response of the bearings at low, intermediate and high strain levels using a single set of parameters. Numerical simulations are carried out of a base-isolated building subjected bidirectional earthquake excitation. An ensemble of earthquake records are selected based on site hazard characteristics and used for a performance based assessment of the building.

A0599- Vertical vibration of end-bearing pile groups in viscoelastic soil layer

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An analytical solution is proposed for calculating the steady-state impedance factors of pile groups with arbitrary pile members subjected to harmonic vertical loads. A new interaction factor between two piles are introduced by definition on the basis of soil resistance instead of pile displacements, to consider the effect of pile geometry on pile-soil-pile interaction. Stress distribution of the soil around the vertically vibrating pile is first determined to define the interaction factor. Accordingly, impedance factors of the pile group are derived using the new defined interaction factor and the popular principle of superposition. Finally, numerical results are obtained for typical parameters to investigate the pile geometry effects and offer insight into the mechanism of load transfer between piles and their surrounding soils.

A0614- Balance design based on the horizontal and vertical collapse margin ratios of steel frame structures

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The collapses of steel frame structures under strong earthquakes have raised many questions regarding the adequacy of the current seismic provisions to prevent a partial or total collapse. They have also brought up questions as to what are the typical collapse mechanisms for the building structures, what is the inherent safety margin in code-designed structures in both lateral and vertical directions, how to strengthen the structures to effectively increase such margins, and how to balance these margins to optimize the overall safety of the structures. This paper presents a methodology to improve the global collapse resistance of the structures by balancing the collapse margin ratio (CMR) in both lateral and vertical directions. Based on the concept of safety balance design, the characteristics of unbalanced design are identified to develop a series of steel frame structures with typical failure mechanisms. The safety assessment of each example structure, in term of horizontal and vertical CMR, is performed. The outcomes permit to develop the envelope of CMR, which reflects the relationship between the two CMRs. The superposition of the parameters of the structural collapse sensitivity to the envelope of CMR allows identifying the critical CMR values in both lateral and vertical directions.

A0673- Seismic vulnerability of railway network based on the running-trains safety evaluation

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The medium-small earthquakes could induce the high-speed train derailment on bridges without any bridge structural damage, leading to the railway lines blockage. For depicting the seismic hazard scenario of high-speed railway network, a framework is proposed to investigate the connectivity vulnerability of China high speed-railway network under the effect of regional earthquake. Based on a dense bridges network covering an earthquake-prone area of southwest China, the PSHA is performed to get the seismic hazard parameters of every bridge site. As a result, the acceleration response spectrum corresponding to different earthquake recurrence interval is obtained. After vehicle-bridge-earthquake dynamic analyzing, the seismic induced derailment probability of vehicles moving on the bridge is obtained and taken as the closing probability of the nodes in the network. Based on the node closing probability corresponding to different levels of earthquake, the Order-X network connectivity algorithm is presented to calculate the network connectivity. The results show that the difference between the micro-zoning intensity and macro-level intensity, which leads to the difference in hazard assessment results for bridges, is the key factor that cause the difficulties of connectivity vulnerability analysis, hence, the safety evaluation of running-trains on bridges is indispensable for the seismic vulnerability analysis of the bridges network.

A0754- Seismic response analysis of liquid pipes in building

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The liquid pipes in the building are used as non-structural members attached to each floor, which is of great significance for ensuring the normal use of the building. Based on the influence of each floor of the main structure on the pipeline, establishes the main structure-pipe integral coupling model and the pipeline multi-point excitation model to analyze the seismic response of the pipeline, and compares the results of the two to propose a multi-point excitation pipeline seismic response analysis method.Through the time-history analysis of the 7-story frame structure, the influence law of ground motion intensity variation on the acceleration amplification coefficient of each floor is obtained., and the seismic response of the floor response spectrum analysis pipeline is established.

A0851- Multiscale random fields-based damage modeling and analysis of concrete structures

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A new approach towards incorporating the stochastic nature of damage constitutive relations is presented for the finite element analysis of concrete structures. Within the framework of stochastic damage mechanics, the spatial variability of concrete is modeled as a two-scale stationary random fields. At the micro-level, the damage evolution law of concrete is mapped to a random field corresponding to the microscopic fracture strain. At the macro-level, the strength distribution of concrete components forms a lognormally distributed random field. The covariance constraint is developed to bridge the gap between the two-scale random fields such that the scale-of-fluctuation of the random material property is satisfied in both scales. Taking advantage of the stochastic finite element method, both the microscopic random damage evolution of concrete and the fluctuation of macroscopic structural responses can be numerically represented. Stochastic structural modeling and damage analysis regarding a high-rise reinforced concrete structure is carried out to illustrate the proposed method. It is shown that the nonlinear behavior of the structure subjected to strong dynamic actions may exhibit significant variability and even its intended collapse modes may be altered merely due to randomness in microscale of concrete.

A0883- Dynamic testing of a full-scale frp-retrofitted reinforced concrete building frame

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Many existing reinforced concrete buildings designed in accordance with pre-1971 codes are generally dominated by weak column-strong beam behavior under seismic loading due to inadequate reinforcement detailing. This behavior can lead to premature failure under seismic loads from damage concentrated in the first story of the structure. This paper presents full-scale dynamic testing of a non-ductile reinforced concrete frame retrofitted using a fiber-reinforced polymer jacketing system on the first story columns. This retrofit scheme was determined based on visible damage patterns and locations (e.g. flexural, shear and lap-splice failure on the first story columns) of an as-built test frame. The full-scale dynamic test was performed to investigate the dynamic performance of the retrofitted building structure in terms of the modal response, inter-story drift, and effectiveness of the fiber-reinforced polymer jacketing system. The results demonstrate that the retrofit scheme helped develop a more uniform story drift distribution, working to counter the soft-story mechanism commonly found in reinforced concrete frames designed during this period.

A0899- Multi-scale comprehensive simulation of concrete shear wall models: numerical simulation

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Concrete structures are widely used in the world, particularly in China, where most areas are earthquake prone zone, therefore their safety is of great importance. The prediction and simulation of such structures under strong earthquakes are essential to the performance evaluation and reliability assessment. However, due to the uncertainties in material properties and numerical modelling, the accurate simulation of complex concrete structures is still a great challenge. The lack of knowledge in the constitutive law of concrete, for instance, is one of the uncertainties that is most essential to the simulation. In recent years, a stochastic damage model for concrete material has been developed. This mesoscopic physical model can capture the mechanical behavior of concrete. In the present paper, the prediction of response of a structural model in shake table tests is conducted by different constitutive laws, including the concrete damage plastic model (CDP) which is embedded in the ABAQUS software, the stochastic damage model (SDM) and the stochastic damage model with softening effect (SDMs). The simulation results of these constitutive laws are compared with the test results, showing that the SDM and SDMs performance better than the CDP. The result demonstrates that to adopt appropriate constitutive law of concrete, including the involvement of compound effects of concrete and reinforcement, is essential to the simulation of strong nonlinear behaviors of concrete structures.

MS13: Damage and Failure Modeling and Analysis of Concrete and Structures

A0119- A fracture problem with a surface energy in the Steigmann-Ogden form

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A problem of a straight mixed mode non-interface fracture in an infinite plane is treated analytically with the help of complex analysis techniques. The surfaces of the fracture are subjected to surface elasticity in the form proposed by Steigmann and Ogden. The boundary conditions on the banks of the fracture connect the stresses and the derivatives of the displacements. The mechanical problem is reduced to a system of singular integro-differential equations which is further reduced to the systems of equations with logarithmic singularities. It is shown that modeling of the fracture with the Steigmann-Ogden elasticity produces the stress and strain fields which are bounded at the crack tips. The existence and uniqueness of the solution for almost all the values of the parameters is proved by reducing the system of singular integro-differential equations to the system of weakly-singular integral equations. It is shown that introduction of the surface mechanics into the modeling of fracture leads to the size-dependent equations. A numerical scheme of the solution of the systems of singular integro-differential equations is suggested, and the numerical results are presented for different values of the mechanical and the geometric parameters.

A0124- MULTILEVEL MODELING OF FIBER-REINFORCED CONCRETE AND SIMULATION OF CRACKING IN TUNNEL LINING SEGMENTS

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Aiming at the model-based analysis, design and optimization of engineering structures such as segmental tunnel linings made of fiber-reinforced concrete (FRC), a multilevel modeling framework consisting of a series of model components is developed, which facilitates the investigation of the effect of various design parameters (concrete class, fiber property, fiber distribution, etc.) at different length scales. The fundamental ingredient at the level of single fibers is an analytical model allowing the prediction of the pullout response of a steel fiber, either straight or with hooked end, with or without inclination with respect to the loading direction. For an opening crack in a specific FRC composite, employing the single fiber pullout model, the fiber bridging effect is computed via the integration of the pullout responses of all the fibers intercepting the crack, taking particularly the anisotropic fiber orientation into consideration. Based on the numerically integrated results of crack bridging effect, the corresponding analytical surrogate function form of the traction–separation relation is derived. For the numerical analysis of fracture processes and failure mechanisms at the structural level, the finite element method using interface solid elements equipped with the traction–separation law obtained from the crack bridging model is used to capture the cracking phenomena and the postcracking ductile behavior of FRC. An implicit/explicit integration scheme and an adaptive mesh-processing technique are implemented to enhance the robustness and to reduce the expense of computation. Having these model components validated, the complete multilevel modeling framework is applied to the simulation of failure behavior of tunnel lining segments made of FRC, demonstrating good performance in following the influence of different design parameters from the single fiber level to the scale of engineering structures. Therefore, the present work constitutes the essential ingredients of a “virtual laboratory” for the design and optimization of FRC materials and structures.

A0274- NUMERICAL INVESTIGATION OF CONCRETE AGE EFFECT ON SHEAR LOAD CAPACITY OF POST-INSTALLED ANCHORS

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Fastening systems are widely used engineering solutions supporting innovative demands in design. Fasteners are used to connect structural members or attach secondary elements. Additionally, they see many others applications such as strengthening existing structures/ structural members. The present investigation focuses on the shear load capacity of anchors installed in concrete close to an existing edge. The dominant failure mechanism in this case is concrete cone breakout. This failure mechanism has been investigated for many years, and as a result, different analytical models have been derived as a function of embedment depth and edge distance, in the latter case with varying success. These models seem to be valid solutions for designing safe and reliable fastening systems. Nevertheless, none of them considers the complex aging nature of the heterogeneous material concrete. In design concrete is considered a homogenous material with spatially constant material properties. However, in reality the mechanical properties are functions of the local cement hydration degree, rather than time, which not only depend on the mix design but also on the history of the environmental boundary conditions (i.e. temperature and relative humidity). Consequently, the concrete volume involved in the forming concrete breakout body is characterized by gradients of material properties (and potentially also shrinkage strains) that do not scale with the edge distance. Furthermore, a so-called wall-effect is known to exist, i.e. the concrete close to the surface differs in composition and material properties from the bulk. This contribution presents a large experimental campaign comprising shear tests on post-installed bonded anchors for three concretes, two ages and three edge distances each. Tests include a full fracture mechanical characterization at both ages, calorimetry, creep, and shrinkage tests. A discrete multi-physics framework is applied in order to investigate the influence of the edge distance on the concrete shear capacity explicitly accounting for (i) the wall-effect, (ii) curing related gradients in material properties and, thus, aging, and (iii) the distribution of shrinkage strains and early age damage. The Lattice Discrete Particle Model (LDPM) is used to simulate concrete at the meso-scale and to mimic its heterogeneity while the degree of curing is determined by the hygro-thermal chemical (HTC) model.

A0378- Analytical model of rocking elements with damaged corners

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The restraints at the joints of rocking structures are released so that rocking motions can occur during earthquakes. Damage to the main structure is limited by the concentrated displacement at rocking interfaces, while corners of reinforced concrete rocking elements crush during the rocking motion. The rocking element exhibits a nonlinear behavior due to the absence of tensile resistance in the end section in prerocking phase. A new analytical model which refers to an existing analogous spread plasticity model of rocking elements is developed to calculate the deformation of damaged rocking elements before rocking based on virtue work principle. A damage influence coefficient is proposed to consider the effects of damaged corners on the entire rocking elements, with a new effective stiffness ratio accounting for the plastic deformation in calculation. The analytical model is verified by the finite element model simulation and the results of existing experiments. The results indicate that the analytical model proposed in this paper could accurately predict the deformation of rocking elements before and after damage. The effective stiffness ratio related to the normal stress distribution at the contact surface is proved to be applicable in the analysis of rocking elements before rocking. By adjusting the damage influence coefficient, the effects of different damage degrees of corners on the stiffness of rocking elements can be explicated. The damage influence coefficient increases as the range of damaged corners increase, which finally decreases the lateral stiffness of the entire rocking element.

A0463- Simplified modal properties analysis of soil-base-isolated-structure systems with large aspect ratio

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A simplified methodology is rigorously studied in this paper to analyze seismic response of base-isolated structures with dynamic soil-structure interaction (SSI) being considered. The proposed methodology is developed based on the existing simplified methodology which is only applicable for non-isolated structures. The base-isolated structure model with two degrees of freedom is supported by swaying and rocking springs and by the corresponding dashpots. Rigorous mathematical derivation is performed, and closed-form formulas of natural periods, modes and modal damping ratios are derived. Furthermore, the overall accuracy of the proposed methodology was checked against the results of the rigorously derived complex eigenvalue approach proposed by Constantinou and Kneifati. A parametric study is also conducted on the SSI effects of base-isolated structures, which turns out that tall and slender structures with stiff isolation systems are more affected by SSI effects in comparison to flexible superstructures. The proposed method provides a feasible way to evaluate SSI effects of base-isolated structures efficiently during the schematic design phase.

A0466- A NEW MODEL FOR DUCTILE FRACTURE PREDCTION WITH STRESS TRIAXIALITY AND LODE DEPENDENCE: MODELLING AND CALIBRATING

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Fracture prediction is of great importance in structural steel in order to simulate the progressive damage and collapse of steel structure buildings. When fracture occurs in critical components, such as beam-column connections, the structural performance including the load transfer paths and load-resistance mechanisms may be different, which may lead to an overestimation of structural performances against progressive collapse, leaving a potential threat to human lives. However, previous studies on ductile fracture of structural steels are relatively limited. In this paper, a new ductile fracture model was developed based on microstructural analysis of fracture process including void nucleation, growth and coalescence. A series of fracture tests were carried out by using Q690D steel to calibrate and verify the newly proposed model. These tests including tensile tests of smooth and notched round bar specimens and shear specimens were expected to fail at different stress triaxiality regimes. It is found that the numerical predictions agree well with the experimental results, which demonstrates the new model can describe the ductile fracture behavior with high accuracy.

A0504- Development and Identification of Hysteresis Model for Reinforced Concrete Columns Failing in Different Modes

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Reinforced concrete (RC) columns have three different failure modes during earthquake excitations, respectively flexural failure mode, flexural-shear failure mode and shear failure mode, then exhibiting different hysteresis characteristics such as strength deterioration, stiffness degradation and pinching phenomena in applications. Thus, the development of an effective and computationally efficient hysteresis model is crucial for the evaluation of seismic performance of existing RC columns. However, the available hysteresis models are rather complicated and the parameters involved in the hysteresis models often lack physical interpretation, which largely prevents its flexible applications in practice. Therefore, a simplified hysteresis model is first proposed in this study with seven model parameters to describe the different hysteresis loop of RC columns under different failure mode. Then, the differential evolution (DE) algorithm is employed to identify the value of hysteresis model parameters by comparing with the experimental data of 251 RC columns under quasi-static testing. Based on the identified value of hysteresis model parameters, a comprehensive comparison of critical model parameters is finally made to provide a quantitative understanding on the difference of the three different failure modes. According to the investigation, it is found that the hysteresis model developed with the seven model parameters is adequate to capture the typical hysteresis characteristics of RC columns under different failure mode. The DE algorithm is also effective to identify the value of hysteresis model parameters. For RC columns failing in flexural-shear mode and shear mode, severer strength deterioration, stiffness degradation and pinching phenomena can be observed. Therefore, a practical way should be further established to estimate the value of hysteresis mode parameters based on the critical physical parameters of RC columns for facilitating its applications.

A0604- Three-Dimensional Finite Element Modelling of UHPFRC Jacket-Retrofitted Piers Under Cyclic Loading

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In seismic evaluation of highway bridges, reinforcement concrete (RC) piers are critical and vulnerable components. There exists numerous old bridge piers with lower longitudinal reinforcement ratio in China. Recently, the authors proposed a new retrofitted method by using ultra-high performance fiber reinforced concrete (UHPFRC) jacket. Cyclic loading test showed that UHPFRC was a promising material significantly enhanced RC piers' seismic-resistant capacity. In this study, the 3D solid finite element model is proposed, relying on the implicit method, to numerically investigate the effectiveness of UHPFRC jacket. The 3D model integrates the concrete damage plasticity (CDP) model for normal concrete and UHPFRC, the constitutive model for reinforcements including local buckling and low-cycle fatigue, and the strain penetration effect between concrete and reinforcement. The 3D modelling scheme is implemented in the commercial finite element program ABAQUS. The constitutive model for reinforcements is realized in UMAT routine, and the bond between concrete and reinforcement is modelled through UEL routine. The comparison with the test validates the proposed 3D model. The confinement effect from UHPFRC jacket, is analyzed in detail with the numerical tool. The influencing factors of UHPFRC jacket on the effectiveness of seismic retrofit, including the height and thickness, are investigated in detail.

A0635- Spatial correlation in disordered heterogeneous materials

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The fracture patterns and damage localization of heterogeneous materials are strongly influenced by the disorder at microscale. This paper investigates the spatial correlation of strength distribution of basic elements systematically with random fuse model(RFM). With the same level of disorder, the spatial correlation determines different failure modes characterized by transition from ductile failure to brittle failure. The statistical avalanches scaling results also show not only the disorder but also the spatial correlation have great influence on material failure characteristics which link with the first order and continuous phase transition.

A0970- An equivalent strain based multi-scale damage model of concrete

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A multi-scale damage model of concrete is proposed based on the concept of energy equivalent strain for generic two- or three-dimensional applications. Continuum damage mechanics serves as the framework to describe the basic damage variables, namely the tensile and shear damage. The homogenized Helmholtz free energy is introduced as the bridge to link the micro-cell and macroscopic material. The crack propagations in micro-structures subjected to tension and shear are modeled, and the Helmholtz free energy in the cracked micro-structure is calculated and employed to extract the damage evolution functions in the homogenized continuum. Based on the damage energy release rates (DERRs) and damage consistent condition, the energy equivalent strain is used to expand the uniaxial damage evolution to the multi-axial damage evolution. Agreements with existing experimental data that include the uniaxial tensile and compressive tests, the biaxial compression prove the capacity of the multi-scale damage model in reproducing the typical nonlinear performances of concrete specimens. The simulation of reinforced concrete underground diaphragm wall further demonstrates its application to concrete structures.

MS14: Uncertainty Quantification and Reliability-based Performance Evaluation

A0020- ROBUST STATISTICAL METHODS FOR POWER SPECTRUM ESTIMATION FROM MULTIPLE SOURCE RECORDS

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Modern approaches to solve dynamic problems where random vibration is of significance will in most of cases rely upon the fundamental concept of the power spectrum as a core model for excitation & response process representation. This is partly due to the practicality of spectral models for frequency domain analysis, as well as their ease of use for generating compatible time domain samples. Such samples may be utilized for numerical performance evaluation of structures, those represented by complex non-linear models. Utilization of ensemble statistics will be considered first for stationary processes only. For a stationary stochastic process, its power spectrum can be estimated statistically across all time or for a single window in time across an ensemble of records. In this work, it is shown first that ensemble characteristics can be utilized to improve the resulting power spectra by using estimations of the median instead of the mean of multiple data records. The improved power spectrum will be more robust in the presence of spectral outliers. The median spectrum will result in more reliable response statistics, particularly when source ensemble records contain low power spectra that are significantly below the mean. As an extension, a weighted median spectrum will also be utilized, based upon the spectral distance of each record from the median, which will shift the estimated spectrum in the direction of the closest samples. To validate the improved method of estimating power spectra wind and earthquake loads are applied to high-rise buildings.

A0131- ANALYZING COMPLEX SYSTEMS UNDER EPISTEMIC UNCERTAINTIES

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Our structures, systems and infrastructure are characterized by a rapid growth in scale, complexity and interconnection with a significant involvement of diverse human behaviour with critical influence, so that uncertainties and risks are involved to a greater extent than ever before. These structures, systems and infrastructure are, to a significant extent, critical for the functionality of our economic and societal life, and thus, require proper approaches and measures to verify and ensure their reliable performance. Reliability and performance analysis, however, become increasingly complicated due to uncertainties and complexity. The realistic quantification of uncertainties and their numerically efficient processing in complex analyses are the two key challenges in this context. This keynote lecture addresses these two challenges. Approaches to deal with epistemic uncertainties are discussed, with focus on imprecise probabilities and in the context of structural and system reliability assessment. The concept of survival signature is presented to analyse complex systems efficiently. Novel pathways to capture interdependencies between systems while estimating their reliability efficiently in a time dependent manner are discussed. Engineering examples are presented to demonstrate the capabilities of the approaches and concepts.

A0179- EFFICIENT BRIDGE LIFETIME ASSESSMENT BY TRAFFIC LOAD MODEL UPDATING AND SUBSET SIMULATION

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We demonstrate a proof-of-concept study on efficient bridge lifetime assessment using limited amount of traffic load data. Conventional approach fits a standard distribution, such as a normal distribution, with observed traffic load in a given period. Then, the distribution is used to predict future traffic load, leading to the final lifetime assessment of a bridge. As the reliability estimation of a bridge depends heavily on the rare traffic load effect events, the conventional approach is inefficient and inaccurate for practical purposes. We propose a more effective use of the traffic load data using a better bridge reliability assessment framework. Our framework involves a real-time updating loop composed of two computational modules: (1) a traffic load simulation model continuously trained by real data, and (2) a machine learning model for bridge response prediction trained by the updated traffic load model. A reliable simulation model can guarantee the supply of sufficient data for accurate reliability assessment, and a machine learning model can speed up the reliability estimation process. To further improve the efficiency of our algorithm, we employ the popular subset simulation method to estimate extremely small failure probability values. The proposed framework is validated by simulated examples.

A0203- Stochastic Stay Cable Force Modeling Using Monitoring Data from a Cable-stayed Bridge

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The monitoring data of cable force, cable temperature from a cable-stayed bridge were analyzed. The daily average values of cable force and cable temperature are used to eliminate the variation effects of one day's temperature. Then the data of cable force and cable temperature were linear regression analyzed. The results showed that the coefficient of determination was about 0.3 and the residue was symmetrically around the regression line. The residue cable force variation alone time was then modeled as potentially Gaussian and homogeneous stochastic fields. Autocorrelation functions and marginal probability distribution functions were determined for the residual radius stochastic field. It was found that the residual value of cable force was stationary and the marginal distribution did not reject normal distribution. The stochastic model of cable force that eliminating the effects of cable temperature was established based on above studies.

A0222- Multi Level Moving Particles Simulation for Reliability Assessment with Approximate Limite State Functions

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Markov Chain Monte Carlo simulation methods allow estimating small failure probabilities efficiently, even for problems that involve a high-dimensional vector of input random variables. Subset simulation can be considered as the most prominent method in this class. In subset simulation, the failure probability is computed as the telescoping product of larger probabilities that require sampling from conditional distributions. Recently, an alternative to subset simulation in the sense of particle methods has been proposed, where a threshold is associated to each sample, samples are moved to new positions in the design space and the number of moves for the initial samples to reach the failure region are counted and yield an estimator for the failure probability, which is of comparable accuracy and efficiency as the subset simulation estimator. The algorithm allows for an easy parallel implementation. Just as for subset simulation, sampling from conditional distributions is required when moving a particle. In most practical applications, the limit state function is approximated numerically with a certain numerical error h. In order to obtain an efficient simulation algorithm, it is necessary to balance the statistical error and the numerical error. In this presentation, a multi level moving particles simulation method is proposed that balances both errors by computing a telescoping sum of estimates for the number of moves. For each term in the telescoping sum, it is necessary to compute as corrector the difference of the number of moves for each initial sample with two consecutive accuracy levels using the same random numbers in the Markov Chain Monte Carlo simulation. For the multi level moving particles method, the sample variance decreases with decreasing numerical error. Thus, the number of samples that has to be evaluated with high accuracy is reduced compared to a single level computation. Therefore, the proposed algorithm is very efficient for problems where highly accurate evaluations of the limit state function are necessary and require a huge computational effort.

A0389- Prestressed Concrete Beams Failing due to Web-crushing: Uncertainty and Reliability analysis

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Shear failure in prestressed concrete beams with stirrup reinforcements and relatively thin webs may be governed by web-crushing failure. In this scenario, the concrete diagonals would crush before the yielding of the shear reinforcement, resulting in a brittle failure mode. An accurate method for predicting web-crushing failure is paramount since web-crushing is catastrophic and could occur without warning (brittle failure). The accurate prediction of the web-crushing strength of beams is an involved process. Consequently, many codes of practices have resorted to implementing simplified methods for predicting web-crushing failure in beams. Therefore, it seemed reasonable to assess how well the design procedures can predict the web-crushing strength in prestressed concrete beams. The paper aims to investigate the model uncertainty and bias related to EC2 web-crushing function using the comprehensive database that is exclusively focused on prestressed concrete beams with web-crushing failure. The measured web-crushing strengths from the experimental tests are compared with the unbiased predicted web-crushing strengths obtained from Eurocode 2. Correlation and regression analysis was also conducted to expose its dependency on some of the essential variables affecting web-crushing strength. The model uncertainty and bias related to the unbiased EC2 design function for predicting web-crushing failure was found to have a mean value $\mu_E = 1.05$ and standard deviation $\sigma_E = 0.15$. The derived model factor observations were shown to be sensitive to the amount of shear reinforcement $\rho_w f_{ywm}$ and beam width b_w. Subsequently, the derived model error statistics were used as input to assess the implicit safety level of EC2 design function for web-crushing failure. Reliability assessment using the FORM procedure was conducted to highlight the safety performance regimes obtained for a limited parametric range of $\rho_w f_{ywm}$ where web-crushing failure governs. The concrete strength, stirrup spacing, yield strength of stirrups, geometrical properties and model error were all treated as random variables. The results indicated an increase in estimated reliability index (β) values as shear reinforcement $\rho_w f_{ywm}$ increases and a decrease in reliability as concrete strength f_{cm} increases.

A0421- Bearing capacity fitting and unfavorable geometric defects analysis of steel arch based on multiple response surfaces

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For a complex failure equation(e.g. implicit and highly nonlinear), the accuracy of the conventional response surface method is limited by the variation of random variables and the number of sample points, which may lead to the inaccuracy of the fitting failure equation and the inaccurate approximate design point .Therefore, many improved methods are proposed to perform reliability for large structure ,and the multiple responses surface method is used to fit the failure equation of the steel arch structure in this paper. Geometric imperfections will significantly reduce the stability bearing capacity of steel arch structure. In order to reasonably determine the unfavorable geometrical defects of steel arch, the multiple response surfaces method based on subspace division is used to fit the bearing capacity function. Then, according to the Lagrange multiplier method of the extremum of the function, the geometric defects distribution with the lowest bearing capacity is solved. Taking the two hinged circular steel arch as an example, considering the change of parameters such as the load ratio and the number of deviation nodes, the bearing capacity analysis results are compared between the proposed unfavorable defects determination method and the consistent mode imperfection method. The results show that: (1) The multiple response surfaces method based on subspace is more accurate in fitting bearing capacity function, and the prediction value of the bearing capacity is close to the result of the finite element analysis; (2) The geometric imperfections obtained by using the fitting function to calculate the extremum are more unfavorable to the bearing capacity,and in the range of parameter analysis, the corresponding bearing capacity is about 10% lower than that obtained by the consistent mode imperfection method. (3) In the range of parameter analysis, with the increase of the number of deviation nodes, the difference between the distribution of unfavorable defects based on multiple response surfaces bearing capacity fitting and the distribution of the consistent defects is further increased, and the positive and negative deviations of nodes of unfavorable defects distribution based on multiple response surfaces bearing capacity fitting are more obvious.

A0423- Structural failure pattern recognition and reliability analysis based on multi-response surface method

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In order to prove the correctness of the calculation results of the multi-response surface method structure analysis software, this paper uses the software to analyze and calculate the space 48-bar transmission tower structure. The author compares the calculated results of the software with those obtained by Monte Carlo method, line sampling method and subset simulation method. It is found that this method is very close to the system reliability calculated by Monte Carlo method, line sampling and subset simulation. The results obtained by this program are satisfactory. Moreover, the number of structural analyses required by this method is the lowest compared with the other methods, which only needs 228. This shows the high efficiency of this method. The traditional failure pattern recognition and structural system reliability analysis methods have two shortcomings: the main failure pattern recognition efficiency is low and the joint failure probability calculation of multiple failure modes is complex. In this paper, an improved simulation method is proposed to identify the main failure modes. Using this method to a classical frame structure is analyzed, and it is compared with the more widely used one, namely, beta boundary method. The results show that a large number of components need to be analyzed for their reliability in the process of identifying major failure modes. However, this method only needs 56 finite element analyses to obtain the same calculation results.

A0440- IDENTIFICATION OF PERFORMANCE DEGRADATION MODEL BASED ON STANDARD WIENER PROCESS

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Wiener process model is a kind of common probabilistic statistical model, which has good computational analysis characteristics and can describe the degradation process of non-monotone system. Therefore, it is one of the most widely used models in structural reliability modeling based on performance degradation. Furthermore, the engineering structure has the characteristics of randomness, fuzziness and time-varying in the service life. Thus, it is considered that the use of Wiener process to describe the degradation process of structure can reflect the actual situation of structural degradation better. In fact, identification of degradation process models is the most important and difficult in the degradation processes modeling. In this paper, we use auto-correlation function method and hypothetical test method to identify model. The first method is empirical, which is suitable for all components to measure performance degradation at the same time and low precision requirement. Firstly, we draw the auto-correlation function graph of the wiener process by MATLAB. Secondly, we collect the degradation data of the concrete dynamic elastic modulus that can be used as a parameter of evaluating durability, then obtain the auto-correlation function of the data and supplement it with the graph. Finally, we compare the graphics of the two, it can be seen that they are similar in appearance, so we can preliminarily determine that the degradation process conforms to the wiener process. Compared with the first method, the second is more reliable, which uses probability statistics method to test whether the degradation of dynamic elastic modulus of concrete satisfies the definition of Wiener process. Firstly, we adopt Shapiro test method to examine the normality of the data by the R-Studio; the results show that the W-value is close to 1 and the P-value is greater than 0.05, it explains that the data obey the normal distribution. Besides, we use the linear regression method to fit mean and variance of the data on this basis, the results is that the correlation coefficient R of the mean, ut and the variance,

$\delta^2 t$ is close to 1 and P-value near 0, so it is considered that the degradation data of dynamic elastic modulus adheres to a normal distribution with an average of ut and variance of $\delta^2 t$. Secondly, we respectively use ADF test method and LBQ test method to examine the stability and independence of the data, the ADF results reflect that P-value is less than 0.05 and the LBQ results display that P-value is greater than 0.05, it means that the increment process is stable and independent. In conclusion, we can judge that the concrete dynamic elastic modulus degradation satisfies definition of Wiener process. On this basis, we can predict the residual life of the structure and provide a scientific basis for the later maintenance and reinforcement of the structure. In addition, we also can evaluate the reliability of the existing concrete structural durability and provide a reasonable design basis for the proposed structure, thus reduce the construction cost of the engineering structure at maximum extent under ensuring the safety.

A0449- A NeW unbiased metamodel method for Efficient reliability analysis of structures with multiple failure modes

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As a widely used method for structural reliability analysis, the metmodel method can reduce the computational cost substantially. However, there always exists error due to the approximation of the metamodel to the Limit state function (LSF), resulting in a biased estimator of the failure probability. In order to overcome the difficulties of the metamodel method, the authors developed an unbiased Kriging metamodel method. The basic idea is to formulate the unknown failure probability as a product of the Kriging metamodel-based failure probability and a correction term which accounts for the error due to metamodel approximation. The correction term is estimated efficiently with the Markov chain simulation by introducing an intermediate event which is the union of the actual failure region and the metamodel-based failure region. However, practical engineering structures often have multiple failure modes. It's hard to obtain initial samples from the failure regions, which makes it infeasible to perform Markov chain simulation and estimate the correction term. What's more, Markov chains start from one failure region has few chances to jump to another failure region. Therefore, contributions of different failure regions to the failure probability cannot be properly accounted for. In order to tackle the difficulty of the unbiased metamodel method when applied to problems with multiple failure regions, this paper proposes a modified version of the unbiased Kriging metamodel method. The proposed method consists of three steps: 1) builds an initial Kriging metamodel with such an accuracy that the metamodel can capture the global behavior of the real LSFs, 2) proposes an adaptive clustering algorithm to obtain representative samples from the failure regions, based on the built Kriging metamodel, 3) estimates the failure probability with the unbiased Kriging metamodel method. The first step is implemented by using the metamodel construction stage of the Meta-IS method. The Kriging model is adopted as the metamodel here, although any other metamodel is applicable. An intial Kriging metamodel is built with a few samples generated by Latin hypercube sampling (LHS). Then the Kriging metamodel is updated sequentially with samples from an importance density constructed based on current metamodel. The update process is conducted until the target accuracy is achieved, which guarantees that relative error of the metamodel is in the order of magnitude of 1. In general, the metamodel with such an accuracy can capture the major failure regions. Based on the last updated metamodel, an adaptive clustering algorithm is employed to identify the failure regions. The Davies-Bouldin (DB) index is adopted as the clustering validity index. Clustering that minimizes the DB index is the optimal clustering. Each cluster corresponds to a sub-failure region. And the cluster' centroid is chosen as the representative sample of each one of the failure regions. Based on the obtained samples of the failure regions, the correction term is calculated by Markov chain simulation. Following the procedure of the unbiased metamodel method, the failure probability is estimated by multiplying the correction term by the metamodel-based failure probability. Several numeric examples are provided to demonstrate the proposed method.

A0487- SPARSE PARTIAL LEAST SQUARES REGRESSION-POLYNOMIAL CHAOS EXPANSION METAMODELING METHOD

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To circumvent the curse of dimensionality and multicollinearity problems of traditional polynomial chaos expansion approach when analyzing global sensitivity and structural reliability of high-dimensional models, this paper proposes a sparse partial least squares regression-polynomial chaos expansion metamodeling method. Firstly, an initial estimation of polynomial chaos expansion coefficients is obtained with the partial least squares regression. Secondly, according to the principle of maximum sparsity under the allowance of regression error threshold, polynomials which have strong correlation with the structural response are adaptively retained with the penalized matrix decomposition scheme. Next, an updated estimation of the polynomial chaos expansion coefficients is obtained with the partial least squares regression. Sobol sensitivity indices are obtained with a simple post-processing of the expansion coefficients. Finally, the metamodel is greatly simplified by regressing with important inputs, leading to accurate estimations of the failure probability without additional computational cost. The results show that with acceptable accuracies, the new method overperforms the traditional counterpart in terms of computational efficiency when solving high-dimensional global sensitivity and structural reliability analysis problems.

A0518- Global dynamic Seismic Reliability analysis for RC Frame structures Using nt-ANN

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Global reliability of structures based on system-level limit state functions is an efficient and approximate approach to system reliability analysis for complex structures under dynamic disaster actions. However, the global limit state variable (GLSV) is generally an implicit function of the basic random variables (RVs). Furthermore, the dimension of the basic random variables is another bottleneck problem to the practical applications of this approach. Monte Carlo simulation (MCS) and meta-model techniques are good alternatives to overcoming these problems. However, MCS as well as its different variants require substantial sample points and cost enormous computing resources for accurate estimations. The meta-models such as ANN, also have the problem of curse of dimensionality. In this paper, an ANN meta-model based on number-theoretic point-selection strategy (NT-ANN) is developed to analyze global dynamic reliability analysis of reinforced concrete (RC) frame structures under seismic actions. To uniformly fill the space of basic RVs and reduce the required number of sample points, the good lattice point approach in the number theory is utilized to replace the Latin hypercube sampling approach. Two global limit state functions for RC frame structures are considered: global deformation limit state and global damage limit state. The BP forward ANNs are trained as the meta-models for the two global limit state functions. A two-sided evolutionary power spectrum model considering the non-stationarities in both intensity and frequency is chosen to model the random process of the stochastic ground motion. Furthermore, the randomness of structures is also considered. Then, the global dynamic reliability indices for the two system-level global limit states of RC structures under seismic actions are calculated by the developed NT-ANN method. The accuracy and efficiency of the proposed method are verified and compared by the subset simulation technique.

A0540- Estimating uncertainty in limit state capacities for reinforced concrete frame structures through pushover analysis

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In seismic fragility and risk analysis, the definition of structural limit state (LS) capacities is of crucial importance. Traditionally, LS capacities are defined according to design code provisions or using deterministic pushover analysis without considering the inherent randomness of structural parameters. To assess the effects of structural randomness on LS capacities, ten structural parameters that include material strengths and gravity loads are considered as random variables, and a probabilistic pushover method based on a correlation-controlled Latin hypercube sampling technique is used to estimate the uncertainties in LS capacities for four typical reinforced concrete frame buildings. A series of ten LSs are identified from the pushover curves based on the design-code-given thresholds and the available damage-controlled criteria. The obtained LS capacities are further represented by a lognormal model with the median m_C and the dispersion β_C. The results show that structural uncertainties have limited influence on m_C for the LSs other than that near collapse. The commonly used assumption of β_C between 0.25 and 0.30 overestimates the uncertainties in LS capacities for each individual building, but they are suitable for a building group with moderate damages. A low uncertainty as β_C =0.1~0.15 is adequate for the LSs associated with slight damages of structures, while a large uncertainty as β_C =0.40~0.45 is suggested for the LSs near collapse.

A0549- Study on Mechanical properties and damage assessment for Collided Concrete

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With the rapid development of transportation, the accidents of vehicles hit the superstructure of bridges have occurred frequently. However, the existing codes and standards do not have the mechanical performance index of collided concrete. At present, it is difficult to obtain the mechanical properties and damage degree for collided concrete, and the maintenance design for collided bridges cannot be carried out. In this paper, finite element (FE) numerical simulation and model tests are employed for assessing the damage degree for collided concrete based on Acoustic Emission (AE) technology. Firstly, the whole process of collision for concrete standard specimen is simulated by using the finite element software. Meanwhile, based on the simulation results, 24 group concrete standard specimens are made and the concrete falling hammer collision test is conducted with considering different cases. After comparing the results of collision force time history curve, stress and peak strain. It is found that the values of numerical simulation agree well with the values of model test, and the correctness of the numerical simulation can be verified. Secondly, the AE technology is utilized for analyzing the damage degree between collided concrete and non-collided concrete, the results show that the strength of collided reduce obviously, and the brittleness with an growth trend, the abrupt change characteristics of AE can be used to determine the stages of micro-crack formation, expansion and destabilization for the concrete, and the damage degree of concrete can be reflected. Finally, based on the relationship between energy rate and relative stress, the damage degree of collided concrete can be obtained according to derive the damage factor for collided concrete. It can provide scientific basis for damage assessment of collided concrete.

A0558- A novel machine learning - based method to protect member buckling for square pyramid space grid structure

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A novel model is proposed to determine whether there is member buckling in the square pyramid space grid structure under the design load condition based on the supervised machine learning classification algorithm. The random defects of the structure are generated through the Monte Carlo probabilistic design method, and the statistical characteristics of the structural defects are assumed to obey the normal distribution. Then the displacement of the selected response characteristic points under the lower virtual load condition (Load1) and the members buckling state under the design load condition (Load2) are calculated by ABAQUS for the defective square pyramid space grid structure. The input-output correspondence between the response point displacement and the member buckling state is established. Input and output data sets are established through calculating a large number of structural model with different defect levels. Then, Support Vector Machine, Naive Bayes classification and Nearest Neighbor were used to analyze the accuracy of the prediction model. Lastly, the effects of the position and number of response points and the virtual load conditions on the accuracy of the prediction model are further analyzed, and the optimal prediction model scheme is obtained.

A0580- A new fractional moment equations method for nonlinear vibration analysis

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A novel method based on fractional moment equations and copula moment closure is proposed to approximate the dynamic response of a stochastic nonlinear systems. The method is behind the concept that probabilistic density function (PDF) of the response is capable of characterizing the full random characteristics of stochastic response. Our approach relies on the derivation of moment equations that describe the dynamics governing the two-time statistics. These are combined with a non-Gaussian PDF representation for the joint response-excitation statistics, based on the copula functions. Through the adopted PDF representation, we derive a closure scheme which involving the fractional order statistics of the response and the closure constraint. The dynamics constraint is also derived directly through the moment equations. The derivation of PDF is based on the maximum entropy principle in which constraints have mentioned above. Numerical examples presented in the paper illustrate the numerical accuracy and efficiency of the proposed method in comparison to the Monte Carlo simulation method and Gauss closure of integer moment.

A0583- A Kriging-HDMR metamodel method for system reliability analysis of structures

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The reliability analysis for real structures that involve multiple failure modes are extremely complicated and computational expensive. The most challenging problem is to identify sub-failure domains and to obtain the sample's information. From this point of view, we proposed an efficient reliability analysis method for complex structural systems on the basis of Kriging-HDMR metamodel. Firstly, the Pseudo-Markov Chain simulation was employed to identify the failure domains. The Markov Chain Monte Carlo (MCMC) method was then used to simulate failure samples of the sub-failure domains. For each sub-failure domain, the sample which has the maximum PDF among the simulated MCMC samples was selected as the design point. These design points were employed as the reference points to build Kriging-HDMR metamodel for each sub-failure domain, respectively. By weighted summing the Kriging-HDMR metmodel of all the sub-failure domains, a global Kriging- HMDR metamodel of the structural system was obtained. Finally, Monte Carlo simulation was used to estimate the failure probability by calling the global Kriging-HDMR metamodel. The proposed method can significantly improve the accuracy and efficiency of the reliability analysis of structures with multiple failure modes, which offers effective alternative for the commonly used methods. Two numerical examples were presented to demonstrate the proposed method.

A0613- STUDY ON CORROSION FATIGUE RELIABILITY OF STEEL BOX GIRDER DETAILS OF CABLE-STAYED BRIDGE BASED ON NEURAL NETWORK

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In this paper, the corrosion fatigue behavior of steel box girder is studied. The direct effect of corrosion and the coupling effect of corrosion and fatigue are considered in the reliability study. The corrosion fatigue problem of local weld details of steel box girder of cable-stayed bridge is studied from the point of time-varying reliability. Aiming at the problem of time-varying reliability evaluation of corrosion fatigue for local weld details of steel box girder of cable-stayed bridge, the following aspects are studied. Study on time-varying model for corrosion fatigue resistance, the attenuation law of steel strength due to corrosion is obtained firstly, and then the influence law of corrosion on the fatigue strength of steel box girder is determined according to the functional relationship between fatigue strength and steel strength. On this basis, the time-varying model of corrosion fatigue resistance is established according to mathematical statistics theory. For the study of time-varying model of corrosion fatigue load, the variation law of corrosion depth of steel box girder with time is determined firstly, then the dimension parameters are modified in the finite element model according to the time-varying law of corrosion depth, and then the time-varying stress amplitude of steel box girder is calculated based on the applied time-varying load of automobile fatigue. On this basis, according to mathematical statistics theory, the corrosion fatigue load time-varying model is established through uniform design and neural network technology. For the study of time-varying reliability of corrosion fatigue, the explicit function expression of the time-varying model of corrosion fatigue resistance and load is determined firstly. The explicit function expression of the time-varying model of corrosion fatigue resistance is obtained according to the modification of corrosion function to fatigue strength. According to the response surface regression, the explicit expression for the time-dependent model of corrosion fatigue loading is obtained. Then the time-varying function of corrosion fatigue is

established by explicit function expression of time-varying model of corrosion fatigue resistance and load, and the time-varying reliability index of corrosion fatigue is calculated by FORM method. Finally, taking Sutong Bridge as the research object, the time-varying reliability analysis of corrosion fatigue reliability of weld details of steel box girder of cable-stayed bridge is carried out by using the method proposed in this paper, and the sensitivity analysis of parameters is carried out. Through the above research, the time-varying models of corrosion fatigue resistance and load effect are established, and the expressions of corrosion fatigue resistance and load effect in the calculation of corrosion fatigue time-varying reliability are established. A method of time dependent reliability analysis of corrosion fatigue for members of steel box girder of cable-stayed bridge is presented. The proposed theory, method and algorithm are applied to the actual bridge engineering. The factors affecting the corrosion fatigue reliability of steel box girder of cable-stayed bridge are analyzed quantitatively and the sensitivity of parameters is analyzed. The trend analysis of corrosion fatigue performance of steel box girder of cable-stayed bridge is given respectively.

A0644- A New ANALYTICAL Approach for Solving the First-Passage Probability of the Continuous Markov Process

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The analysis of first-passage probabilities in stochastic processes is a key problem in the evaluation of structural reliability. In this work, the continuous Markov process was studied in detail to obtain new methods for solving its first-passage probabilities. First of all the conventional Poisson process method was used to analyze the first-passage probability of continuous Markov process and it was pointed out that Poisson process method cannot solve the first-passage problem of a general continuous Markov process. Then the Markov property of the continuous Markov process was used to calculate the first-passage probability of a continuous Markov process. This new method includes the following analysis steps. First integrate the transition probability density function of the Markov process to obtain the transition probability distribution function. Then based on the total probability formula and the transition probability distribution function, the relation of the probability distribution function of the first-passage time of the Markov process and the one dimensional probability distribution function of the Markov process can be obtained by mathematical deduction. And the one dimensional probability distribution function of continuous Markov process can be obtained through the transition probability density function and the initial condition of the Markov process by integration. Thus the probability distribution function of the first-passage time of the continuous Markov process can be solved finally, by which the first-passage probability can be calculated easily. The results indicate that analytical expressions for the first-passage time probability distribution function of the continuous Markov process can be derived using elementary mathematical methods, through the Markov property of the process. The resulting analytical solution doesn't require the use of assumptions in its calculations. The new analytical method based on the Markov property of the continuous Markov process produces highly accurate solutions. Finally, as an application example, a continuous Markov process was used to simulate structural performance degradation. It is used to represent the time-varying amount of structural degradation at any point in time, leading to a non-stationary stochastic model for the degradation process, which will provides a scientific basis for an estimation of the structural durability and reliability of concrete, and the formulation of a rational fortification and maintenance schemes for concrete structures.

A0753- A polynomial element based Galerkin approach for the simulation of multivariate random fields

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Uncertainty simulations related to spatially varying random properties require the theory of random field discretization. It is known that a random field in definition consists of an infinite number of random variables that are attached to every point of the simulation region. The utility of Karhunen-Loève (K-L) expansion allows one to represent the random field as the summation of a series of deterministic functions. By this way, statistical approximation of the spatially varying random property can be realized by means of a finite number of random variables. However, the K-L expansion depends crucially upon analytical eigen-solutions of the Fredholm integral equation of the second kind. Especially with an emerging requirement for a multivariate random field simulation along with complex geometries, the exact K-L expansion is seldom applicable for realistic engineering problems. To this end, a polynomial element based Galerkin approach is introduced in the paper to deal with the integral eigenvalue problem for complex geometries. To implement, various types of high-order elements are derived based on orthogonal polynomials in numerical analysis. Besides, to deal with high-dimensional integrals produced by the multivariate Galerkin projection, the Gauss-type numerical interpolation schemes are presented to approximate the true but computationally demanding covariance functions. To access numerical accuracy of the polynomial element based Galerkin approach, the convergence rate is assessed by means of global variance and covariance errors. Several examples including the reproduction of spatially varying fiberglass density field along with the NACA0012 airfoil geometry are presented to illustrate engineering applications of the Galerkin approach. Results have shown the polynomial element based Galerkin method is effective for numerical simulation of multivariate random fields along with complex geometries in various engineering domains.

A0771- Construction Monitoring for the Heavy Truss Lifting Project in Changsha, China

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The under constructed Ice-snow Joy World project in Changsha is the largest indoor amusement park among the world which was also the only public structure with the ice-snow theme that constructed above the discarded huge pit. The global structure is composited by the 60-m mass concrete supporting columns, the 3×10^4 -m 2 concrete platform and the 1.8×10^4 -ton steel truss roof. A lifting project was initiated to build the roof system which was constructed by the large-span trusses with huge self-weight, and the large component cross-sections has leading a great welding operations for the lifted structures. The firstly lifted 600-ton primary truss was approximately 48-m long, 8-m deep and was welded by the series of thin-walled box steel, which was lifted by four groups steel cables inside the steel tubes. The integral lifting process was planned to complete for 27 m hoisting height within 6 hours. To evaluate the operation risk and require the practical demands of structure performance during the construction process, a real-time remote monitoring system with 10-mins sampling time was designed and implemented to measure the stress status of structural components. The multiple vibratory-wire strain gauges were deployed in this project to measure and monitor the stresses in different locations, where ten gauges were arranged in the primary truss and eight gauges were arranged at the bottom for each of the two-side supporting columns with distributed data-acquisition equipment to measure the strain releases during the construction process. The actual tested strain measurements showed that the primary truss exhibited the acceptable levels of strain that were below steel yielding limits, which indicating that a safe status was performed by the structure during the lifting process. And the stress status of two-side supporting columns were consistently kept in a certain range, which indicating that a stable lifting operation was investigated without larger tilt and vibration or abnormal conditions. And the out-of-plane movements was not occurred during the lifting process. Minor changes of stress conditions were investigated for the primary truss during the subsequent boundary welding operation, while the stress in supporting columns was continuously diverged within an acceptable range until the welding operation was completed. The measured stress distribution characteristics was confirmed by the finite element (FE) model to ensure that the construction behavior of the primary truss system was reliable during the global process.

A0830- Quantifying Post-disaster Functionality Losses and Recovery of Community Building Portfolios

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Assessing community resilience requires estimation of post-disaster functionality losses and recovery of its building portfolios. This study proposes a physical-based probabilistic framework for quantifying the functionality loss and recovery of spatially distributed buildings within a community, as an integrated system. The framework includes three modules: (1) First, a novel building portfolio functionality metric (BPFM) is proposed, which is a measurable, scalable, and actionable indicator of a building portfolio's capacity to respond and recover from a hazard event. (2) Second, a building portfolio loss estimation (BPLE) approach is developed to quantify the functionality losses (measured by BPFM) of building portfolios immediately following the hazard probabilistically, by propagating uncertainties throughout hazard characterization, spatial damage evaluation, and spatial functionality loss estimation. (3) Third, conditional on the functionality losses quantified in previous step, a building portfolio recovery model (BPRM) is developed. The BPRM is a two-level stochastic simulation model — modeling the building-level restoration as a discrete state continuous time Markov Chain (CTMC) and modeling the portfolio-level recovery by spatial aggregation of the individual building's CTMC process over the entire recovery time horizon. In the end, the entire framework is implemented to a testbed community — Shelby County, TN, under scenario earthquake hazard.

A0912- Analytical solution for local buckling strength of square CFT columns subjected to eccentric compression

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In the research and design of local buckling of concrete filled steel tubular (CFST) members, the local buckling characteristics of circular or square CFST members under axial compression are studied. However, the theoretical and experimental studies on the local buckling characteristics of CFST members under eccentric compression have not been reported. In engineering practice, concrete filled square steel tubular columns are widely used as eccentrically loaded members, and the local buckling characteristics of the steel tube wall are not clear. In this paper, the local buckling behavior of the steel tube of concrete filled square steel tubular eccentrically loaded columns is studied theoretically.It is assumed that both the loaded and non loaded edges of the square steel tube columns are fixed constraints, and considering the effect of concrete filled in the steel sheet, that is, assuming the rigidity of the concrete filled in the steel sheet, the steel sheet can only buckle outward.Take longitudinal 1.5 wave (wavelength a) for research, an analytical solution of local buckling stress of concrete filled square steel tubular eccentrically loaded columns is derived by means of energy variational method. Furthermore, it is found that the local buckling strength σcr decreases significantly with the increase of width-thickness ratio b/t when the stress gradient is constant, and the local buckling stress increases with the increase of stress gradient when the width-thickness ratio is constant. When the stress gradient coefficient is 0, that is, axial compression, the local buckling coefficient of the steel tube reaches the minimum value of 10.312; when the stress gradient coefficient is 2, that is, pure bending, the local buckling coefficient of the steel tube reaches the maximum value of 22.713. When concrete-filled square steel tubular columns are subjected to uniaxial eccentric loading, the local buckling strength of each steel plate of concrete-filled square steel tubular columns is different because of the different stress state. In order to maximize the use of the strength of concrete-filled

square steel tubular columns, the local elastic buckling should be avoided before the steel yield, the concrete-filled square steel tubular plates critical local buckling stress is greater than its yield strength. Finally, the reasonable width-thickness ratio limits of each steel plate of concrete filled square steel tubular eccentrically compressed columns with different stress gradient coefficients are given. Satisfying the limits can ensure that no local elastic buckling occurs before the steel plate yields, which can be used as a reference for engineering design.

A0915- Risk Priority numbers for various failures in bridges

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One of the important and a systematic method that is used for identification of failures of any system is FMEA (Failure Mode Effects Analysis). This is done through identification of the most important causes of all the failure modes of the system under consideration. This identification can be easily achieved through the description of all failure modes of the system under consideration. FMEA is based on the concepts of probabilistic analysis. A corresponding equivalent deterministic method has been developed by Dytczak and Ginda (2017). This paper describes in detail the application of this method to bridge failures. Based on actual data. The results are also compared with those obtained using the well known FORM (First Order Second Moment) method. This will enable the engineers to rank various failures and take necessary steps to mitigate the risk. These results will be useful to both academicians and practicing engineers.

A0944- Reliability analysis of seismic capacity of shear wall considering possible tension failure and random eccentricity

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In 2010 Chile earthquake, it is found that some RC shear wall structures have been seriously damaged, which necessitates great significance to study reliability of the structures. Considering the factors of flange, abdominal reinforcement area and restrained edge members, the seismic capacity reliability index is analyzed for typical shear wall structures. Firstly, we used PKPM and ETABS software to establish typical shear wall structures of 15 and 33 stories, and analyzed the ranges of the load effect ratio values of rectangular section and I-section shear wall models under different seismic intensity. Then, the Monte Carlo method is used to calculate reliability index for shear wall structures with different parameters (e.g. sections, load effect ratios, reinforcements) considering possible tension failure and random eccentricity. The influences of restrained edge members of different types on reliability are also analyzed. The results show that: (1) the reliability will reduce by increasing the axial compression ratio for the shear wall under the same design eccentricity; (2)the reliability of shear wall with restraint of end column is the highest, and that with restraint of concealed column is the lowest; (3)the vertical distributed reinforcements of the shear wall and the reinforcements at the end of the flange wall have a great influence on the reliability, and the reliability index of the shear wall can be improved largely by increasing the area of the end reinforcements.

A0949- Structural failure mode identification and reliability analysis based on multi-response surface method

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In order to prove the correctness of the calculation results of the multi-response surface method structure analysis software, this paper uses the software to analyze and calculate the space 48-bar transmission tower structure. The author compares the calculated results of the software with those obtained by Monte Carlo method, line sampling method and subset simulation method. It is found that this method is very close to the system reliability calculated by Monte Carlo method, line sampling and subset simulation. The results obtained by this program are satisfactory. Moreover, the number of structural analyses required by this method is the lowest compared with the other methods, which only needs 228. This shows the high efficiency of this method. The traditional failure pattern recognition and structural system reliability analysis methods have two shortcomings: the main failure mode identification efficiency is low and the joint failure probability calculation of multiple failure modes is complex. In this paper, an improved simulation method is proposed to identify the main failure modes. Using this method to a classical frame structure is analyzed, and it is compared with the more widely used one, namely, beta boundary method. The results show that a large number of components need to be analyzed for their reliability in the process of identifying major failure modes. However, this method only needs 56 finite element analyses to obtain the same calculation results.

MS15: Environmental Effects on the Properties of Cementitious Materials: Experiments, Modeling and Simulation

A0526- Experimental Research on Dynamic Characteristics of Crumb Rubber Concrete at Low Temperature

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The rubber concrete can effectively use the waste rubber. Combining the pulverized rubber powder into the concrete can significantly improve its toughness, crack resistance, heat insulation, noise reduction performance, impact resistance and energy dissipation performance. In some high-altitude and cold regions of China, there are many airport runways, highways, roadbed sleepers and bridge pier, which are subjected to various loads at low temperature. Systematic study on the dynamic properties of rubber concrete at low temperatures is urgently needed and will promote the engineering application of rubber concrete. In the past few years, we carried out some experimental study and theoretical analysis of the dynamic compression performance, impact resistance and energy dissipation performance of concrete specimens with two rubber particle sizes and four rubber contents at low temperatures of -30 °C, in order to provide a basis for the application of rubber concrete in pavement engineering in cold areas. The main research work of this article is as follows: The dynamic compressive properties of low temperature rubber concrete under three loading rates were studied. The dynamic compressive strength and deformation properties of rubber concrete increase with the increase of stress rate, and they are higher at low temperature of -30°C than those of normal temperature at 25°C. And the increase of strength is related to the temperature. The dynamic increase factor of rubber concrete at low temperature is lower than that at normal temperature, which shows that the sensitivity of rubber concrete at low temperature is lower. With the increase of rubber content, the dynamic compressive strength

of rubber concrete decreases and the deformation performance increases continuously. And the deformation of rubber concrete at low temperature is greater than that at normal temperature. Moreover, with the decrease of rubber particle size, the dynamic compressive strength of rubber concrete decreases, and the deformation slightly increases. The impact resistance of rubber concrete under low temperature conditions was studied. Compared with room temperature, The initial and final cracking times and ductility indice of rubber concrete at low temperature have a certain degree of decrease. The decrease magnitude of rubber concrete is smaller at low temperature, and the failure process also becomes smooth, indicating that the mixing rubber powder into concrete has significant role in improving ductility at low temperature. Regardless of temperature, the difference between the initial crack and the final crack is the largest when the rubber content reaches 20%. The ductility index of concrete specimens with 20 mesh rubber powder is greater than that of concrete with 50 mesh rubber powder. When the concrete is incorporated rubber powder with particle size of 20 mesh and content of 20%, the impact resistance of rubber concrete is the best at low temperature. Because the discreteness of data on impact resistance of rubber concrete at low temperature, the Weibull distribution theory is introduced to study the distribution law of the numbers of impact. The results show that Weibull distribution theory can better describe the distribution rule of rubber concrete impact times well. The low-temperature energy performance of rubber concrete was studied. After the low temperature, the hysteretic curve of rubber concrete tends to be full, and the energy performance increases significantly. With the increase of the magnitude of loading force, the loss factor of rubber concrete increases, and the increase rate of loss factor of rubber concrete at low temperature is smaller than room temperature. And with the increase of rubber content, the total hysteretic energy consumption growth rate of rubber concrete at low temperature of -30°C is faster than that of room temperature 25°C. The loss factor of rubber concrete with large particle size is larger than small particle size. And greater rubber content results in the more significant rate of increase of loss factor.

A0542- Engineering application of rubber concrete in airfield pavement and its performance

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In order to explore the engineering application of rubber concrete in airfield pavement, contrast experiments on pavements with ordinary concrete and rubber concrete were carried out in Ningxia province of China. Based on the results of four experimental tests on damping, impact resistance, temperature susceptibility and impermeability, rubber concrete shows better performances than ordinary concrete. The average attenuation ratio and average damping ratio of rubber concrete is 1.5 times and 1.6 times the value of ordinary concrete, respectively. The lower failure destruction degrees of rubber concrete in the free fall test showed the better impact resistance. And the good thermal storage capability and superior deformability were observed in the test of temperature susceptibility. What's more, the seepage of ordinary concrete is 3.4 times the value of rubber concrete within 40 minutes. In the expeditious freeze-thaw experiment, after 300 freeze-thaw cycles, the loss of quality and relative dynamic modulus of rubber concrete met the standard requirements. Moreover, the relative dynamic elastic modulus of rubber concrete is 8.6% higher than that of ordinary concrete after 300 freeze-thaw cycles. All the advantages of rubber concrete are beneficial to the applicability of the airport pavement, and it is expected to improve the anti-attack capability of the airport pavement and enhance its protection and safety capabilities. It also solves the problem of freeze-thaw damage of cement concrete pavement in high altitude areas, and can meet the urgent needs of our country to build airport pavements in high altitude areas of the plateau.

A0774-STRAIN MONITORING IN CONSTRUCTION OF LARGE-SCALE REINFORCED CONCRETE PLATFORM

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The Ice-snow Joy World in Changsha was built on top of the abandoned pit, in which thirty-three concrete-filled steel tube columns were distributed to support the global structural weight and the reinforced concrete platform was constructed to bear various types of loads. The long-span platform with an area of 3×10^4 -m^2 was composed of the cast-in-place prestressed box concrete beams, I-beams and the steel truss floor. Since the structure dead-weight is considerably heavy and the engineering has long construction period, it is indispensable to carry out long-term strain monitoring on the complex platform structure during the construction process of the Ice-snow Joy World, in particular the multi-span continuous girder beams with a section height of 5 m, on which external force, deformation or temperature stress may have significant influences to cause additional internal stress. A strain monitoring scheme was designed and the measurement stations were mainly arranged in the parts with large deformation and sensitivity predicted by theoretical calculation. There totally contains 196 strain sensors pre-embedded in the main beams to obtain a series of strain data as well as the temperature for monitoring the dynamic status of the structure under construction and for further studies. The beam strain monitoring system contributes to know about the invisible tiny deformation of the components and infer the stress state and mechanical characteristics along with time change and varying environment. Besides, temperature sensors were layout in the mass concrete volumes to observe the inner temperature differences, which was aimed to avoid critical cracks due to the significant stress gradient effect during casting. After a period of data collection and analysis, some conclusions can be drawn from the intuitive strain and temperature curves, which reflected the resulting stress changes of individual beam under construction and service, and it revealed the connection between the stress field and temperature field of mass concrete structures. For a

validation of the reliability of the strain monitoring system and structural safety performance, simulation computation using a finite element (FE) method was carried out to compare the peak strains between the measured value and the simulation result during the construction, and the measured value was consistently within admissible stress in different construction stages, indicating that the design requirement was achieved. Therefore, the structure strain monitoring can effectively inspect the real-time state of stress on site and evaluate the safety of the structure under construction and service condition, providing basis for practical construction and engineering design.

A0805- STOCHASTIC DYNAMICAL BEHAVIORS OF CONCRETE REACTION SYSTEM IN CONCRETE SUBJECTED TO EXTERNAL SULFATE ATTACK

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A numerical methodology is proposed in this article to investigate the stochastic dynamic behaviors of the corrosion reaction system in concrete under sulfate attack. First, we provide an in-depth discussion of the chemical Langevin equation for elementary reactions and the deterministic rate equation for composite reactions. Then, the chemical Langevin equation for composite reaction (CLE-CR) is derived according to the law of mass conservation and random process theory. The stochastic kinetic equation for corrosion reactions in concreter (SKE-CRC) subjected to sulfate attack is proposed by applying the CLE-CR to a series of actual sulfate-induced corrosion reactions. The developed SKE-CRC incorporates the randomness from system parameters, initial conditions, and internal noise into the corrosion reaction system. A series of experiments are performed to validate the effectiveness of the proposed method. The results calculated from extensive stochastic simulations are expressed in terms of the likelihood and extent of the concentration of corrosion products. The experimental result is only one possible outcome of the random event, and it has a certain probability. The results of this study indicate that the dynamical behaviors of the corrosion reaction system in concrete can be comprehensively described if a reliable probabilistic approach is employed instead of conventional deterministic approaches.

A0812- STOCHSTIC MODELING OF SULFATE ION DIFFUTION COEFFICIENT AT THE CONCRETE-SOLUTION INTERFACE

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A stochastic model of sulfate ion diffusion coefficient under multiple factors is proposed in the paper. Based on Fick's second law, the effects on the diffusion process from porosity, water-to-binder ratio and stress ratio of concrete are comprehensively discussed. The calculated results are compared with the experimental data in the literature. The analysis results of the stochastic model fit well with the experimental data. This indicates the rationality and reliability of the model. Compared with the conventional deterministic diffusion coefficient model, the stochastic model can reflect the evolution process of the diffusion coefficient with different conditions. And the probability density functions (PDFs) of the diffusion coefficient at the different times can be obtained conveniently. In addition, it is also shown that the randomness of the coupling effect of sulfate and external load essentially comes from the microstructure porosity affecting its macroscopic diffusion process. Therefore, the random distribution of porosity can be treated as the main factor considered in the proposed stochastic model of sulfate ion diffusion coefficient.

A0814- SELF-HEALING OF ENGINEERING GEOPOLYMER COMPOSITES WITH FLY ASH AND METAKAOLIN

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Self-healing characteristics and mechanism of Engineered Geopolymer Composites using fly ash and metakaolin (MFA-EGC) at various tensile preloadings of 1.0%, 2.0% and 3.0% exposed to air and wet/dry cycles conditioning regimes were experimentally investigated. The results show that MFA-EGC combines the advantages of traditional ECC and geopolymer, exhibiting obvious multiple cracking pattern and a strain-hardening behavior. The crack spacing ranges from 2mm to 5mm and the maximum residual crack width is below 25μm, which provide more favorable conditions for self-healing. After rehealed subjected to two environments, number of cracks decreased significantly. The average tensile strain capacity measured can exceed 3.8%, and both ultimate tensile strain and strength of the majority specimens at reloading are higher than that of virgin specimens without any preloading. Air conditioning encourages the self-healing of the MFA-EGC materials. Amorphous aluminosilicate phases with gel-shape resulting from geopolymerization reaction are verified as main self-healing product growing in the crack and PVA fiber surface by SEM-EDS, XRD and FT-IR, which may be enhanced the bond of fiber and matrix interface, leading to the recovery of the tensile properties.

A0817- PREPARATION AND CHARACTERISTICS OF PVA FIBER REINFORCED ENGINEERINGED GEOPOLYMER COMPOSITES INCORPORATING METAKAOLIN AND FLY ASH

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Under activating by alkaline solution prepared by sodium metasilicate and sodium hydroxide, the preparation of Engineered Geopolymer Composites using fly ash as the main raw material and metakaolin as auxiliary material was studied, and the performance of uniaxial direct tensile and characteristic of the geopolymer were also explored. The results show that the geopolymer has good multi-cracking behavior after uniaxial direct tensile test. The distribution of cracks is uniform, and the crack spacing is in the range of 2-5mm, and the average width of residual cracks is about 25μm. The tensile strength for the optimum proportion at 3d, 7d and 28d was 3.2MPa, 3.7MPa and 3.8MPa respectively, and the tensile strain could be up to 6.8%, 6.4% and 5.2% respectively. The order of influence of factors on the tensile properties was as follows: curing temperature ＞ metakaolin content＞ fiber content. Through the three-point bending and the single-crack tensile test, it is shown that the calculated pseudo-strain hardening (PSH) indexes is consistent with the trend of ultimate tensile strain by the uniaxial tensile test, which can well explain the high ductility. The results of XRD, FT-IR and SEM show that a large number of amorphous geopolymeric gel were produced during the geopolymerization reaction, covering around spherical fly ash particles, and the symmetric stretching Al-O/Si-O bonds and Si-O-Si bending bond were observed.

A0953- Multi-Phase Modelling of Multi-species Transport in Cementitious Materials: In case of Electrochemical Rehabilitation

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Existing reinforced concrete structures experience severe durability degradation when subjected to alkali–silica reaction (ASR) and chloride attack. A special electrochemical rehabilitation treatment, containing lithium compound anolyte, has been developed to drive lithium ions into concrete as well as remove chlorides simultaneously, for mitigating both the ASR-induced cracks and the chloride-induced corrosion. Good performance of introduced lithiums in controlling ASR-induced expansion has already been proved. Unfortunately, the migration mechanism of lithium in concrete under an external electric field is seldom investigated in existing literature. In this study, with help of the “double-multi” model, the efficiency of impregnation of lithium ions and simultaneously the removal of chloride ions through a specific electrochemical treatment are numerically evaluated, which results into the distribution profiles of all typical ionic species. The heterogeneous concrete model examines the aggregate effect, especially on the interaction with lithiums which are supposed to mitigate ASR. The ionic interaction between different species and the electrochemical reaction at electrodes are also considered. Through a relative thorough modelling of multi-phase and multi-species, a systemic parametric analysis based on a series of significant factors during electrochemical treatment (e.g., current density, treatment time, temperature, cathode position and concentration of lithium solution) reveals some important tendencies of ionic electromigration in concrete, which are supposed to guide the field application.

A0966- Research on Moisture Transport of Cement-based Materials Based on Low Field Nuclear Magnetic Resonance

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The microstructure test of cement-based materials based on NMR is conducted. Under the conditions of different water cement ratio, ratio of aggregate to cement, silica fume content and SAP content, the variation of the most probable aperture and porosity of cement-based materials are researched. The research shows that the most probable aperture and porosity of samples with water-cement ratios of 0.5 and 0.6 increase by 2.22nm, 7.16nm and 4.56%, 9.09%, respectively. When S/C is 1, the porosity of sample decreases by 3.85%. The increase of silica fume content can reduce the most probable aperture of the sample, but increase the porosity. When the silica fume content is 5%, 10%, the porosity increases by 2.73 %, 3.83% respectively. If the sample is doped with SAP, the most probable aperture and porosity are increased when the content is 0.15%, and when the content is increased to 0.3%, the most probable aperture and porosity are reduced by 4.01nm, 1.12% respectively. It can be found to play a good internal maintenance role in an appropriate amount. Based on one-dimensional frequency coding technology, the moisture transfer test of cement-based materials is conducted. The moisture distribution curves under different factors are obtained through one-dimensional frequency coding tests. It is found that the silica fume reduces the fluidity of the slurry, so the internal distribution of the sample is not uniform, water distribution curve fluctuates up and down. Absorption height h and water volume per unit area i of sample increase rapidly first and then slowly with time. The growth trend is consistent with the variation of porosity. When water absorption time is 7d, h and i of the samples with water-cement ratio of 0.6 are the largest, 51.97mm and 9.48 mm3/mm2. Based on the experimental results, key parameter models for water transport are constructed. The models of water volume per unit area and height of water absorption under different factors are constructed. Based on the existing model, models are established between sorptivity S, capillary coefficient k and microstructure, and the relationship between S and k is discussed. It is found that the ratio between S and k can be expressed approximately as the two times of the porosity. The saturation distribution and the Boltzmann transformation of the moisture distribution curve are calculated, and then the moisture diffusion coefficient is calculated using the existing model. The diffusion coefficient model under different influence factors is finally obtained.

MS16: Fluid-Structure Interactions and Flow-Induced Motions

A0159- Wind-induced cladding and structural loads on low-rise buildings with 4:12-sloped hip roofs

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The characteristics of wind-induced cladding loads on building surfaces were examined regarding different parameters of roof shapes, building plans, horizontal dimensions, etc. A wind tunnel experimental study for low-rise buildings with 4:12-sloped hip roofs was performed in a simulated open terrain exposure at the Building Aerodynamics Laboratory of Concordia University, Montreal, Canada. Furthermore, finite-element analysis, applied to the experimental pressure data, was carried out in order to investigate structural force features for main wind force-resisting frames. Three-dimensional linear computational models with and without cladding (bare frames) with different stiffness ratios and connection conditions of structural members influencing the wind load sharing path were considered. Moreover, comparisons between cladding/frame loads obtained by using experimentally measured pressures and their counterparts evaluated by using American wind load provisions for gable rectangular roofs indicate significant reductions. These comparative studies are expected to be instrumental for future development of wind code and standard provisions.

A0442- Applications of Immersed Boundary Methods in Hydraulic Modeling

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Two immersed boundary methods (IBMs) have been developed for implementing levees/floodgates and 1-D rivers/streams in hydraulic modeling. The IBMs have been originally developed in CFD simulation for flows over moving objects or objects with complex shapes, where the immersed boundaries of the objects do not coincide the grid points. In regional scale hydraulic modeling, because the grid size could be much larger than the widths of the levees/floodgates and some of the rivers/streams, the locations of the levees and rivers could often locate in-between grid points. It is not accurate for the traditional implementation by placing higher or lower land elevations on the grid points to represent the levee/floodgates and streams. Therefore, IBM becomes a good candidate for this type of modeling and simulations. Thanks to the IBM, the structure in-between the grid points can be accurately realized, and the new implementation presents some advantages over the traditional implementation. The IBM implementation also makes it possible to simulation scenario such as the levee collapsing and breaching during the floods, which it is difficult, if not impossible, for the traditional approach to achieve. In this study, the levee/floodgate and one stream were implemented using the IBMs, and the simulation results were compared to the results from the traditional method for validation. Several flooding scenarios were simulated to investigate the effects of storm-surge flood to the coastal wetlands.

A0747- Nonlinear Parametric Vibration Analysis of Radial Gates

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In this work, based on dynamic characteristics of radial gates, a nonlinear vibration equation of the radial gate arm is established. Excitation conditions of primary parametric resonance and subharmonic parametric resonance are obtained by using multiple scales method and numerical method. The parameter analysis shows that: comparing with traditional calculation method of dynamic instability region division, the presented method is more suitable to analysis of parametric vibration for radial gates as considering the end moment, vibration duration and amplitude. The vibration amplitudes of arm increase with the increase of its length and excitation amplitude, as well as the decrease of arm inclination angle. Moreover, the parametric resonance is easier to be excited and its frequency bandwidth is broadened with the initial end moment increasing. Since the vibration response of the arm is influenced by the nonlinear term in the equation, the damping effect is limited. In the further research of vibration reduction control, energy transfer method (e.g. tuned mass damper) should be adopted to achieve vibration reduction control.

A0785- Mode interactions of DEEP-SEA riser IN Shear flow

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Vortex-induced vibration (VIV) is the main problem for in-service deep-sea risers. VIV is essentially a nonlinear, self-excited and self-limited multi-degree-of-freedom resonance response due to the nonlinearities either in structure or fluid. For example, the lock-in response, hysteresis, displacement jump, bifurcation and chaos. The present experimental and finite element analysis (FEA) methods can measure and calculate the response characteristics of risers at specific flow velocity. However, it is rather difficult to investigate the continuous change of VIV response of riser in larger velocity ranges. Based on the Van der Pol wake oscillator model, the VIV cross-flow governing equations of the riser fluid-structure interaction system in shear flow are established. Then the simplified MDOF model with 15th-order modes is derived by Galerkin method. Its bifurcation diagram is obtained by using the method of Poincaré mapping for the velocity of ocean current in a wide range. The characteristics of typical response are analysed based on time history, phase diagram, Poincaré section and frequency spectrum. It is found that there are various phenomena of mode interaction in the system, including 1:3 internal resonance, non-internal resonance and multistable phenomenon. Such as periodic solution and almost periodic solution coexist, periodic solution and periodic solution coexist, and almost periodic solution and almost periodic solution coexist. The characteristics of these phenomena have important reference value for designing the controller about VIV.

A0788- Suppressing Vortex-Induced-Vibration Using Broadband Passive Targeted Ennergy Transfers

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The passive and nonlinear targeted energy transfers induced by resonant interactions between a single-degree-of-freedom nonlinear energy sink(NES) and a 2-DOF vortex-induced-vibration(VIV) model of a cylinder is investigated. It is shown that partially suppress VIV by passively transferring vibration energy from the cylinder to the NES in a one-way irreversible fashion. Numerical parametric studies identify three main mechanisms for suppressing VIV: periodic response, quasi-periodic response and chaotic response suppression mechanisms. We investigate these mechanisms both numerically by Wavelet Transform(WT) and Poincare map method, analytically by a complexification- averaging technique. Each suppression mechanism involves strong 1:1 resonance capture during which the NES absorbs and dissipates a significant portion of energy fed from the fluid flow to the cylinder. Failure of suppression is associated with restoring the underlying triggering mechanism of instability, which is a series of superharmonic resonance captures followed by escapes from resonance. Finally, using a numerical continuation technique, we perform a bifurcation analysis to examine sensitive dependence on initial conditions and thus robustness of instability suppression.

A0972- AcTIVELY-CONTROLLED Turbulence SIMULATIONS AND THEIR Effects on THE AEROELASTIC PROPERTIES OF TYPICAL BRIDGE Deck SECTIONs

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As one of the most advanced experimental tools to reproduce the natural turbulence, a newly-built actively-controlled multi-fan wind tunnel facility was employed to investigate the turbulence effects on flutter derivatives and critical wind velocity of typical bridge decks in this paper, through the sectional model test approach and the free-vibration identification method for flutter derivatives. The simulation of turbulent flow fields including narrow-band and wide-band ones with diverse turbulence intensities and integral length scales is achieved, which is difficult for grid-generated turbulence in conventional boundary layer wind tunnels. Three representative sections, including a thin flat plate, a streamlined single-box girder, and a streamlined twin-box girder with a central slot were considered in this study. The results tend to indicate that turbulence has significant effects on each deck section, meanwhile turbulence intensity and integral length scale each has respective influence on flutter oscillations of bridge decks. The general conclusion seems to be that the more streamlined a section is, the more sensitive to turbulence its flutter derivatives are. At the same time, flutter critical wind velocities have been recorded. It is found that the critical wind speeds under small turbulence intensities are larger than those under the smooth flow, yet under large turbulence intensities the results turn to the opposite. With the increase in integral length scales, the flutter critical wind speeds for all three sections will gradually decrease or increase until they equals the critical wind speed values under the smooth flow. Similar to flutter derivatives, flutter critical wind speeds of streamlined sections seem to be more sensitive to the turbulence. In addition, flutter critical wind speeds based on the two degree-of-freedom coupled flutter equation were calculated using the flutter derivative data identified in the tests. The calculated results are well agreed with the measured ones, which verifies both the flutter derivatives and critical wind speeds from the experiment.

MS17: Stability and Failure of Structures and Materials

A0149- FREQUENCY ANALYSIS FOR VIBRATING BENDING BEAMS VIA A NEW STATIC APPROACH

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The natural frequencies of different vibration modes are useful for the understanding of mechanical properties of engineering structural systems. This study presents a new static approach for solving some free vibration structural systems to determine the natural frequencies of beam models under different boundary conditions. To this end, it is obvious that any static structural systems can be considered as special cases of more general dynamic structural systems. For vanishing time-depended variables, the governing equations of motion can be reduced to static problems. Starting with the basic governing equation for beams subject to a harmonic load and resting on elastic foundation, the governing equation for bending is solved and applied directly to yield the free vibration solutions. Specifically, the key idea is to assume a positive or negative generalized elastic parameter using the static approach to correspond to the real and imaginary frequency parameters via free vibration analysis, respectively. Consequently, an appropriate negative elastic foundation parameter is determined and the natural frequencies can be obtained. Its basic assumption is in the presence of a concentrated load, the deflection of a beam becomes infinite when the stiffness approaches zero. A comparison with respect to classical free vibration solutions is presented and excellent agreement is illustrated. Furthermore, fast numerical convergence of the new approach has also been demonstrated. This static approach for free vibration problems can be extended to the dynamics of more complicated structural systems.

A0247- HAZARD-INDEPENDENT STUDY OF THE STABILITY SENSITIVITY OF THE LOW RISE FRAME SYSTEMS SUBJECTED TO THE EXTREME LOADING CONDITIONS

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From the scenarios of different hazardous events (Hurricane, Flood, Earthquake, Tsunami, Blast, Impact etc.), a need to account for the possible damage is getting utmost importance while investigating the stability of building structures. This paper aims to provide a framework to establish a comparison of stability sensitivity of the frame systems (Steel and RC) in different levels when subjected to the extreme loading conditions. As an effort to avoid cumbersome calculations associated with particular damage events, the works attempts to provide a hazard – independent approach for the application of damaged conditions. Regardless of the event that characterizes specific damage states, significant damage to structural members typically reduces the respective stiffness of the element. This principle is utilized in the hazard – independent damage approach by simply reducing section moduli of the targeted structural member with respect to lateral load direction i.e., the stiffness along the direction of lateral loading is investigated. This procedure results in a weakened, or softened, structural system that is used to approximate the impact on stiffness in global level, and thus the stability of overall system. The work done for the stability sensitivity of Low rise steel moment frames was presented in EMI Conference 2017 held in San Diego. It is extended further to RC moment resisting frames and comparison of some results were demonstrated in EMI Conference 2018 at MIT. The work accounts for the geometric non-linearities of the structural members and the system as a whole. Proceeding further to make it to more realistic scenario, the results from 3D assembly of both RC and Steel Frames will be discussed. AISC approach to softening of section moduli for members to account for plastic residual stresses and that effect of localized plasticity at the section and member level will be investigated.

A0332- ACharacterization of nonlinear constitutive behavior of ceramic-based composite using digital image correlation

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The tensile and compressive behavior of the ceramic matrix composite (CMC), were investigated in varying orientations relative to the 0/90 woven carbon fibers. The ratio of shear to normal stress was about 1-3.73, depending on the fiber orientation. The non-linear stress–strain behavior under combined tensile and shear stress and the linear elastic behavior under compression load were determined through full-filed deformation measurement technique. The coupling between normal and shear stress of the 2D-woven CMC under proportional loading conditions were identified. The off-axis tension test results show that the evolution rate of damage is accelerated under the corresponding combined biaxial tension and shear loads. A novel generalized nonlinear stress-strain constitutive relationship is derived using the complementary strain energy density function and the material properties have been determined through the applied stress and DIC measured strain in material principal coordinate using the least square regression. The nonlinear coupling between tensile and shear stress has been considered in the proposed model. It is demonstrated that the predicted stress-strain behavior under off-axis loading agrees with the experimental measured behavior very well.

A0380- PLY-GAP EFFECTS ON BUCKLING BEHAVIOR OF COMPOSITE CONIC BARREL BY AUTOMATED FIBER PLACEMENT

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Automated fiber placement (AFP) is increasingly used in the manufacturing of aircraft composite structures, since it is a process capable of quality ensurance and cost reduction. However, duo to the geometric effects, ply-gaps inevitably occur in the process of manufacturing composite conic barrel with fiber reinforced plies. As ply-gaps would reduce the mechanical properties of the structures, such as stiffness and stability, it is necessary to establish an analysis method to investigate the ply-gap effects for composite conic barrel. A method combining the analytical solution with the finite element analysis is proposed in this paper. First, the equivalent mechanical properties of the ply with gaps were calculated analytically. Then, field variables were used in the finite element method to relate the variable gaps with the ply equivalent properties in the barrel. The finite element models of AFP composite conic barrel under tensile, compressive and shearing loads were established to perform the linear buckling analysis. The buckling loads and their corresponding buckling modes for the composite conic barrels with and without ply-gaps, respectively, were compared to study the ply-gap effects on the stiffness and stability. Further, ply-gap distributions in AFP composite conic barrel were rearranged, theoretically, to evaluate how the stability can be improved. The analysis results indicated that the ply-gaps can obviously reduce the buckling loads and change the buckling modes of composite conic barrel under tensile, compressive and shearing loads. Adequate ply-gap width control and distribution are effective factors to improve the stability of composite conic barrel manufactured by AFP process.

A0384- Seismic Performance of Unreinforced Masonry Walls with Boundary RC Frame

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Korean government has been intensifying the building seismic regulations for reducing the possible seismic damage of the buildings, and it is especially accelerated after Gyeongju Earthquake in 2016. One of them is to widen the scope of buildings that review seismic design conformity when a building permit is granted. But the mandatory seismic design for the buildings was still restricted to three stories or higher, 1,000 m^2 or more until 2016. And at the same time, it was announced that it would be expanded to more than 2 stories or 200 m^2 by December 2017. On the other hands, most of the detached houses or low-rise residential buildings have been constructed using unreinforced masonry wall in Korea. These conventional unreinforced masonry wall structures were reported to be vulnerable to seismic activity, causing lots of casualty and property losses from the previous earthquake. The reinforced masonry wall structures are considered to be a good engineering solution mechanically, but it will take many years to prepare and distribute all of the industry's infrastructure including structural design, fabrication, and construction to the market. The purpose of this study is to investigate the seismic performance of unreinforced masonry walls which is reinforced with boundary RC frame to check the possibility of replacing reinforced masonry wall structures. Boundary RC frame composes of one tie-beam and two tie-columns in this study. Two specimens are prepared, with the same overall dimension and material properties. 1st test specimen represented a typical unreinforced masonry wall and 2nd test specimen was reinforced with boundary RC frame on the 1st test specimen additionally. Cyclic loading test was carried out to compare the seismic performance of two different test specimens. From the test results, it was found that failure mode of unreinforced masonry wall changed from 'fragile' to 'ductile' fundamentally by the installing of boundary RC frame. Additionally, the increased maximum loads of the test specimen with boundary RC frame corresponding to the same loading schedules results in great increasing of energy dissipation capacity about 2~4 times. Finally, it was concluded that installation of boundary RC frame on unreinforced masonry wall can be a good alternative measure for the replacement of reinforced masonry walls structure in Korea.

A0473- characterization for COMPRESSION-SHEAR COMBINED PROPERTIES of a composite material

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As composite materials have been increasingly used for primary structures on commercial airplane, the ability to measure their complex mechanical properties efficiently and to analyze their failure mechanism with high fidelity becomes even more important. In this study, the nonlinear constitutive law for IM7/8552 fiber-reinforced unidirectional composite material under multi-axial loads has been identified, and furthermore the failure criterion and modes have been discussed accordingly. First, improved short beam shear (SBS) tests were performed, and the data recorded by digital image correlation (DIC) technique was used to characterize the coupled compression-shear stress-strain relationship. Then a compensation scheme by finite element model updating (FEMU) method was employed to approach the material constitutive parameters through the process of correcting the parameters iteratively until the agreement of simulated FEM results with the measured DIC strain field. At last, the uncertainties in DIC data reconstruction and the covariance matrix of the extracted constitutive parameters are discussed too. To demonstrate its advantage, the proposed nonlinear constitutive law was used to analyze deformation mechanism and to simulate the failure modes.

A0586- BUCKLING OF BEAMS SUBJECT TO INFLUENCE OF SURFACE STRESSES

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The micro-electromechanical systems (MEMS) or nano-electromechanical systems (NEMS) are miniaturized structures with micro or nano length scaled features. In such structures, the existence of surface stresses has been reported which may greatly influence the mechanical behaviours of such structures and should not cannot be ignored. The surface stresses may be either induced by mismatching of the material properties between the surface layer and the underlying bulk materials or by the foreign adsorbate on the surface layers. In this study, the buckling behaviours of the beams including surface stress effects are investigated. The bulk core materials of the beams are assumed to be isotropic and the top and bottom layers of beams are covered with atomic thin surface layers and are subject to compression. The Reddy's third order shear deformable beam theory is employed to derived the total potential energy functional of the beam. The Ritz method is then applied to derive the eigenvalue equation which can be solved to obtain the buckling load of the beam. The buckling behaviours of the laminated beams, which include surface stresses, are presented and discussed in details.

A0590- THERMAL POSTBUCKLING BEHAVIOURS OF FUNCTIONALLY GRADED NANOCOMPOSITE PLATES

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The current investigation deals with the thermal postbuckling behaviours of nanocomposite plates consisting of carbon nanotube reinforcements or graphene sheet reinforcements under a uniform temperature field. The material properties of carbon nanotube reinforced composite (CNTRC) and graphene reinforced composite (GRC) are both assumed to be temperature-dependent. Two types of functionally graded patterns for the CNTRC single plate and the GRC laminated plate are proposed. The plates are assumed to rest on a Pasternak foundation with all edges simply supported and in-plane immovable. The Reddy's third order shear deformable plate theory is employed to derive the postbuckling equations which also include the effects of the von Karman geometric nonlinearity. A two-step perturbation technique is used to solve the postbuckling equations and an iteration method is applied in the computation. The influences of the functionally graded patterns and the foundation stiffness on the thermal postbuckling behaviours of the nanocomposite plates will be presented and discussed in details.

A0681- Imperfections by Design: Interactive Buckling and Postbuckling in Architected Materials

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Harnessing elastic instabilities in materials have recently enabled new classes of tunable systems and devices, such as soft fluidic actuator, metamaterial-based artificial muscle, gating mechanism, origami-inspired artificial muscles, nonlinear force sensor, biomimetic actuators at architectural scale, and soft robotics, etc. The common feature of those instability-induced smart systems is the amplifying force and augmented motion compared to their traditional stiff counterparts. Achieving these amplifying effects usually relies on harnessing tailorable architected materials (also known as mechanical metamaterials) as the building block. One of the ongoing challenges is how defects change the properties of mechanical metamaterials to achieve targeted functionalities with aperiodic materials. In response to such need, we introduce a class of shell structures which undergoes interactive buckling induced by strategically controlling the number and distribution of geometric defects. By combining finite-element simulations and desktop-scale experiments, we found that the interactive buckling can be induced by strategically controlled the number and the distribution of defects, leading to a deterministic actuation response compared to the one without geometric defects. Our study thereby opens avenues for the design of the next generation of actuators and robots with high fidelity and low sensitivity over a wide range of length scales.

A0705- Soil Arching Effect Based Study on the Stress Distribution and Failure Mode of the Holes for Under-excavation in Building Rectifying

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In the design of building rectifying with under-excavation method, the deformation and the failure mode of the excavation holes are the key problems. They will affect the determination of the key design parameters such as excavation diameter and the distances of the excavation holes. In this regard, some experiments were carried out to study the stress redistribution, failure mode of the excavation holes. First, a simulation model box was designed with the ability to simulate the soil excavation. Then the soil excavation was done with the hole diameter 200mm, and three cases with hole distances of 400mm, 600mm, and 800mm were adopted. The soil settlement due to the excavation hole was measured. It is found that there are three failure mode of the excavation holes: vertical irregular oval, horizontal irregular oval, irregular circle. Further, it is found that the pressure of the soil will transfer from the upper of the hole to the side soil between the holes, which mean that the soil arching effect occurs. However, due to the cluster holes effect, the relative displacement is small. In this context, the full arching effect cannot be formed. Thus, a new calculation formula is put forward with some modifications to the fully arching effect. The calculation results are compared with the experimental results, which agree well. Furthermore, it is found that as the hole distance becomes bigger, the soil between the holes will form a steady arching foot, which is unfavorable to the building rectifying. Thus, it can be concluded that a critical hole distance exist between steady arching and unsteady arching. It can be concluded from this experiment, 2-3 times of the hole diameter is a proper hole distance for the rectifying design.

A0776- CLASSIFICATION OF STEEL H-SHAPED CROSS-SECTIONS UNDER COMBINED COMPRESSION AND BENDING CONSIDERING PLATE INTERACTION EFFECT

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The cross-section classification concept is an important part of steel structural design. In order to distinguish the plastic deformation ability of cross-sections, the cross-sections of compression-bending members can be divided into four classes according to different plate width-to-thickness ratio limits. However by comparing the width-to-thickness ratio limits of the current specifications including GB50017, Eurocode3, AISC360, AIJ, it is pointed out that most of the specifications do not consider the interaction effects of steel plates of cross-sections. In this paper, steel H-sections were chosen as the main research objects. To consider the plate interaction effect in cross-section classifications, parametric study of steel H-sections with different width-to-thickness ratios and axial force ratios was carried out by software ABAQUS. The finite element model was verified by the experimental results in the related literatures. Through the simulation result it was observed that different width-to-thickness ratios and axial force ratios could lead to different failure modes, bearing capacity and ductility, so the interaction effect of adjacent plate was confirmed. Then the values of M_u/M_{ec} of all the finite element models were obtained, where M_u is the ultimate bending capacity and M_{ec} is the elastic bending moment, within which the dominating parameters of finite element models with M_u/M_{ec}=1 were extracted. Based on these cross-sections with M_u/M_{ec}=1, the fitted function for the classification limit of class 3 and class 4 cross-sections in terms of flange and web width-to-thickness ratios and the axial force ratios was proposed. Finally, the proposed limitations were compared with the specifications including GB50017, Eurocode3, AISC360 and AIJ to further prove its correctness, where it is observed that each specification is relatively conservative compared with the results of the newly proposed limitation. This is mainly because all the specifications except AIJ follow the rule of single plate concept, i.e. the interaction effect between flange and web is ignored. Moreover, considering the interaction effect of adjacent plate is more in line with the actual mechanical properties of plates, and would lead to certain economic benefits.

A0839- FAILURE AND BUCKLING ANALYSES OF COMPOSITE LAMINATES WITH CUT-OUTS: THEORY AND EXPERIMENTS

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Fibre-reinforced composite laminates with cut-outs may exhibit complex failure mechanisms and modes. One of the failure criteria is based on a characteristic length at the edge of the cut-out. However, the determination of the characteristic length is a long-standing difficult issue, and how it is related to the properties and geometric parameters of the laminate remains elusive. Moreover, we also show by experiments that laminates with big cut-outs may exhibit local buckling under in-plane tension. Therefore, first, we shall discuss the determination of the characteristic length, and present our result from a viewpoint of non-local elasticity theory of composites. By combining the predicted characteristic length with the improved Puck's failure theory, we demonstrate that the predicted strength of laminates with circular cut-outs qualitatively agree with the experimental measurements. Nevertheless, we also point out that the relation between the characteristic length and the size of the cut-outs still deserves further investigation. Then, we show our experimental observations of the failure modes and buckling phenomena of laminates with big cut-outs under tension. The failure modes include fracture, splitting, and local buckling. Some laminates may buckle before damage, and the critical buckling load can be calculated by a power law of the size of the cut-outs. Therefore, the predictions of the behavior of laminates with cut-outs should be developed taking into account different deformation and failure modes.

A0875- Buckling of Composite Plates with Reinforced Oval Holes

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As larger passenger windows are being implemented to increase the comfortableness in aircraft cabin, stability of composite fuselage panel with cutout becomes a more severe problem. Reinforcements adjacent to window cutout must be extensively evaluated to keep structural stability under service loads and to optimize structural weight and manufacturing costs. This paper presents experimental and numerical results of laminated composite square plates with reinforced oval-like holes. Composite plates with and without window frames were tested to investigate the effects of window frame on buckling response subjected to shear loadings. Instead of conventional T shaped window frame, flat window frames were fabricated from discontinuous fiber composite (DFC) using compression molding before attaching to the laminate composite plate by fasteners. Eliminating the perpendicular rib benefits structural weight saving and eases the manufacturing process. In experimental tests structural deformation and damage were monitored by both strain gauges and digital image correlation (DIC) equipment. Numerical analysis was conducted using finite element method to simulate the buckling behavior of the composite plates with cutouts. The results from experimental tests and numerical analysis were correlated well, and show that window frames efficiently prevent the compressive region from local buckling.

A0925- Strengthening, Failure and Twinning Mechanisms of Graphene/Copper Composites

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Grain refinement and introducing reinforcements have been two common and effective ways to improve the strength of metals, where interfaces are found to play a critical role in mediating the overall mechanical properties of metals based composites. In this study, the effects of interfaces in Cu//Ni and Cu//graphene nanolaminates on mechanical properties are investigated with MD simulations. It is found that coherent twin interface shows significant strengthening effects via plastic deformation due to the dislocation sinking effects. Graphene reinforcements are then incorporated into Cu matrix, and the underlying strengthening mechanism of graphene and the effect of lamella thickness and failure mode are investigated. Incorporating graphene monolayer is proved to simultaneously contribute to the strength and ductility of the composites. Graphene affected zone is developed and integrated with rule of mixtures and confined layer slip model to describe the elastic properties of NGCu and the strengthening effect of the incorporated graphene. The anisotropic mechanical responses and deformation behaviors of graphene/copper nanolaminates under compression are further explored, dislocation slide and twining are found to be the dominant deformation mechanisms under compression along different crystallographic orientations. A graphene wrinkle facilitated twinning mechanism are observed and analyzed, which may contribute to the manufacture of high-strength metal composite combining the twin strengthening and carbon material strengthening effect.

MS18: Computational Modeling of Advanced Materials and Novel Structural Systems for Hazard Mitigation

A0321- Enhancing Seismic performance of porcelain electrical equipment using base isolation

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As economy develops, the society relies increasing more on electricity. Ensuring the steady supply of electricity during natural hazards like earthquakes is of importance. However, porcelain cylindrical electrical equipment (PCEE), as key component of power supply system, performs badly during earthquakes, which might significantly increase the probability of power outage. In order to enhance the seismic performance of PCEE, base isolation is applied. Three typical PCEEs with different frequencies, are taken as example and their dynamic responses under earthquakes are studied. Effectiveness of base isolation at different periods are compared. Analyses are conducted using finite element method. Results show that base isolation is effectiveness at enhancing PCEE seismic performance. Base isolation can reduce PCEE acceleration and relative displacement responses. The effectiveness of base isolation increases as equipment frequencies increase. The effectiveness of base isolation increases as base isolation period increases. Meanwhile, it should be noticed that the absolute displacement responses of PCEE may increase as BI period increases.

A0360- Characterization and Modeling of Adaptive Rubber Bearing

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In order to systematically investigate the mechanical behavior of an adaptive rubber bearing (ARB), mathematical formulations for nonlinear analyses have been derived from the proposed concept of the ARB. Based on the concept of the force equilibrium via the combination of rubber and the sliding core layer by layer, the mathematical formulations presenting the adaptive characteristics of the entire ARB system can be obtained by way of the series of connections of all layers in the entire device. By virtue of the derived mathematical formulations, the phenomena of the ARB isolator possessing adaptive features can be clearly understood even though it is a completely passive device. Numerical analysis which is in good agreement with experimental results infer that the effective stiffness and damping ratio of the ARB isolator change continually during an earthquake and are controllable through appropriate design.

A0363- Multi-Physics Simulation on Passive Patch Antenna Sensor for Wireless Strain Measurement

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A passive patch antenna sensor is a novel device for wirelessly measuring strain on a base structure. The electromagnetic resonance frequency of the patch antenna is highly related to its dimension. When the antenna sensor is deformed along with a base structure under strain, the resonance frequency change can be identified wirelessly and used to estimate the strain. This research investigates mechanical and electromagnetic behaviors of the patch antenna sensor by multi-physics simulation. A 3D finite element model is built for both mechanical and electromagnetic simulation. In the mechanical simulation, nonlinear constitutive relationship of material is considered for calculating accurate deformation under loading. Dimensions of the deformed antenna model are then used for the electromagnetic simulation, which adopts partially air-filled cavity modelling technique for efficiently calculating the resonance frequency of the patch antenna sensor. The accuracy of this mechanics-electromagnetics coupled simulation is validated through laboratory experiments.

A0368- SECTION AND FINITE ELEMENT ANALYSIS OF SEISMIC UHPC BRIDGE PIERS WITH HIGH STRENGTH STEEL

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Advanced behavior of Ultra High Performance Concrete (UHPC) has led to a growing interest among the construction industry worldwide. Currently, UHPC is used widely in bridge deck joints and connections, and to a less extend in structural components or larger structural applications. The structural and seismic behavior of UHPC for larger components is not fully understood. Moreover, using high strength steel (HSS) with UHPC structural components can open the doors for new design opportunities, but yet need to be studied properly for design optimization and obtained ductility for seismic design. The objective of this presentation is to provide better understanding of the seismic behavior and failure mechanism of UHPC components with conventional and HSS reinforcement (mainly bridge piers columns and bent caps) due to earthquakes. Two-dimensional sectional analysis using a recently developed software, MC-BAM, and detailed three-dimensional (3D) finite element modeling (FEM) is utilized. For the 3D FEM, the validity of Total Strain Crack models, as a readily implemented model in DIANA FEA software, in capturing UHPC bridge piers failure mechanism and plastic hinge behavior is investigated. The UHPC behavior in tension and compression is independently defined using uniaxial stress-strain relationships, which are determined using extensive UHPC material tests. The overall response of UHPC bridge piers under combined axial (gravity) and pushover lateral loads is numerically studied. A reference conventional reinforced concrete bridge pier column is also presented to study the relative increase in seismic displacement and force capacities of UHPC bridge piers. Different reinforcement ratios along with varying reinforcement grades are used to study the effect of larger reinforcement on the overall seismic behavior of UHPC structural components, which can eventually lead to new design strategies.

A0671- System Level Analytical, Experimental and Hybrid Simulation of Resilient Highway Bridges

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This paper presents the main features and analytical, experimental and hybrid simulations conducted to characterize the seismic performance of two structural subsystems designed and constructed around the concepts of Resilient Structures and Accelerated Bridge Construction. The first system focuses on achieving resiliency by utilizing a class of innovative connecting devices, termed "V-connector". It can be used to connect two construction parts in a structural system, e.g., the column and the bridge deck, or the column and its foundation. The V-connector adopts a specially-designed V-shape geometry to establish a connection that forms an isolation layer, while utilizing its intrinsic friction to achieve energy dissipation, both of which are required for seismic resiliency. The resiliency is achieved in terms of the elastic behavior of the bridge components that would otherwise show inelastic behavior using conventional design, like the columns. The connector itself is also supposed to remain elastic during the earthquake. Accelerated Bridge Construction is obtained by assembling pre-manufactured structural parts including the V-connector itself on site. In the second system, the concept of resiliency is incorporated in the form of re-centering behavior of the columns. Re-centering columns are designed to experience only minor damage located at the beam-column interface under the same seismic demands that would cause extensive damage in conventional columns, and to return to their original position after the earthquake by unbonded post-tensioned elements. This results in a significant reduction in the repair costs and downtime. Accelerated Construction is achieved by utilizing pre-cast columns and end beams through an innovative socket connection. The work presented here is an enhancement and a different outlook to an earlier research conducted on similar systems.

A0695- Study on the Impact Resistance Capacity of the Honeycomb Sandwich Panel Based on the Miura Origami Pattern

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Honeycomb sandwich structures have excellent energy absorption capabilities, combined with good mechanical properties and low density. These characteristics make them ideal structure system in many engineer fields, such like civil engineering, transportation industry and aerospace industry. This kind of structure is consist of top and bottom face sheet and a honeycomb core between them. In this paper, a novel honeycomb sandwich panel was proposed by introducing miura origami pattern as imperfection into regular hexagonal honeycomb core. A three dimensional finite element model with micro-structure considered of the novel panel was built to validate the energy absorption property under drop-weight impact load case. Several simulations with different impact energy were conducted and the calculation results including absorption energy, plastic area and indentation depth on the top face sheet were investigated. The numerical results showed that more than 80% impact energy was absorbed by the top face-sheet and honeycomb core. The novel panel absorbed more impact energy in honeycomb core than the traditional one did. And the impacting caused larger plastic area on the novel panel. At the second part, the kinematic and geometry properties of miura pattern were discussed to illustration the energy absorption process of the honeycomb core. The panels with rigid foldable pattern and non-rigid foldable pattern were compared. In addition, the effect of the fold angle and core layer on absorbing impact energy was discussed to propose a design method of novel honeycomb panel which was used to find the optimal structure for absorbing impact energy.

A0729- PRIMARY STRUCTURAL CONFIGURATION INVESTIGATION OF A NOVEL COUPLING ARM CONNECTING TWO FLOATING STRUCTURES

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This study reports the primary study on the configuration of a novel coupling arm system connecting two floating structures under extreme wave condition. The coupling arm consists of circular hollow section tubes, a pneumatic piston and rotational flexible joints. The pneumatic piston is designed to absorb the relative surge motion between two floating structures to prevent potential collision, and the rotational flexible joints are used for resisting the bending loads due to different relative motions. Finite element analyses are carried out to determine the initial number of the flexible joints of the coupling arm. Several analysis cases of the arm configuration with different numbers of the flexible joints are investigated. The analysis cases are then compared in terms of the reaction force of the coupling arm and the rotations of the flexible joints. Finally, the optimized structural configuration for a coupling arm of 25.35m is recommended.

GS1: Stochastic Mechanics and Structural Reliability

A0227- Towards Stochastic Modeling of Tsunamis

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This talk describes a prototype of a next-generation stochastic tsunami model, currently under development within the parallel and scalable Trilinos-based Albany finite element code base. This emerging model differs from its predecessors in that it is based entirely on the full nonlinear 3D incompressible Navier-Stokes equations and is amenable to uncertainty quantification (UQ). The model is expected to accurately represent the nonlinear effects inherent in the physical processes underlying tsunamis (e.g., near-shore evolution of waves) and, when mature, enable probabilistic tsunami hazard analyses. We discuss some preliminary work towards quantifying the model's aleatoric uncertainties arising due to variations in model forcing and geometry (bathymetry, coastal topography land use) using a new adaptive polynomial chaos expansion (PCE) algorithm developed within UQTk, a non-intrusive high-performance library for UQ.

A0454- Multidimensional Stochastic Damage Model for Concrete Under Fatigue Loading

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Staying the framework of classical elastoplastic damage mechanics, a new kind of stochastic damage model that is suitable for multidimensional fatigue loading was proposed based on the one-dimensional damage evolution law established before. To bridge the gap between one-dimensional and multi-dimensional damage evolution, the concept of energy equivalent strain is employed. To exhibit the application of the proposed model, a series of numerical tests was conducted on reinforced concrete beams without web reinforcement, considering the randomness in constitutive relationship of concrete. Two kinds of failure modes were identified in the results, i.e., tensile fatigue failure of reinforcement and compressive fatigue failure of concrete. Also it is discovered that the randomness in concrete is possible to lead to change of failure modes of the reinforced concrete beams under fatigue loading.

A0554- A Generic Framework For Probabilistic Damage Characterisation Using Ultrasonic Guided Wave in The Frequency Domain

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Ultrasonic guided wave (GW) which can be actuated by piezo electric transducers installed on structures has been proven to be sensitive to small and various types of damages. The reflection/transmission coefficients corresponding to various damages has the potential to be damage-sensitive features in the field of structural health monitoring. This study aims at formulating a generic framework for probabilistic damage characterization based on reflection/transmission coefficients. The present work is composed of five core elements that make full use of the Bayesian system identification framework to account for measurement noise and modeling errors in tandem with wave and finite element (WFE) model:(i) Given the damage model of the structure, the theoretical reflection/transmission coefficients can be calculated efficiently using WFE models. (ii) The probabilistic distribution properties of the reflection/transmission coefficients estimated using measured ultrasonic guided waves in the frequency domain are inferred based on complex ratio statistics. (iii) Based on the probabilistic distribution of reflection/transmission coefficients, the likelihood function connecting the theoretical reflection/transmission coefficients containing the parameters to be updated and the measured reflection/transmission coefficients are formulated within a unified Bayesian system identification framework. (iv) Kriging model that provides a surrogate mapping between the probability spaces of the damage parameters to be identified and the theoretical reflection/transmission coefficients are employed to replace a significant number of relatively time-consuming WFE simulations required in the likelihood evaluations by very fast approximate estimates. (v) The transitional Monte Carlo Markov Chain in conjunction with the kriging model is used to sample the posterior probability density function of the updated parameters at a very reasonable cost. Two numerical examples are used to verify the accuracy and efficiency of the proposed algorithm. Results indicate that the fast-numerical strategies proposed in this study can improve the computational efficiency significantly.

A0639- A new stochastic finite element method for structural model updating based on uncertain static data

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This paper proposed a new stochastic finite element method for structural model updating based on uncertain static data. Based on the static condensation technique, a statistical model updating equation associated with element updated factors is established. A high-order perturbation technique is introduced to obtain the coefficients of the power series expansions of the element updated factors. The Tikhonov regularization and truncated singular value decomposition are employed in the process of model updating to solve the discrete ill-posed problems caused by measurement noise. The traditional stochastic perturbation model updating method and Bayesian method based on delayed rejection adaptive Metropolis algorithm are used to compare with the proposed method, which can validate the benefits of the proposed method. Both numerical and experimental examples illustrate the accuracy and efficiency of the proposed method for finite element model updating.

A0641- Generalized Taylor-series solution of eigenvalue of random structure

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A new computational method is proposed for solving the eigenvalue of the structure with random parameters based on the recursive stochastic finite element method and generalized Taylor expansion. For this new method, the eigenvalues and eigenvectors of the random structure are expanded as generalized Taylor-series. The deterministic coefficients in each term of the generalized Taylor-series are obtained by recursive stochastic finite element method, then the approaching function with auxiliary parameter h is added in each term. Due to the participation of the approaching function, the convergence domain of the generalized Taylor-series for the eigenvalue is greatly improved, which makes this new method available for the large fluctuation of random parameters and different from the traditional Taylor series. Numerical example involving a variable cross-section continuous beam indicates that the new method can provide excellent approximations of the eigenvalues compared with the perturbation method and recursive stochastic finite element method.

A0751- A Fractional Moment Method for Reliability Analysis of Structures under the Spatially Variability

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The reliability analysis of an engineering system, structure or component is typically based on a model that describes the system's response, such as deformation, as a function of applied loads, operating environment, material properties and geometry or configuration. Analytical derivation of the distribution of a function of random variables is feasible only in very simple cases and it is intractable problem in a general setting. Especially, the spatially varying uncertainty cannot be handled directly by means of structural reliability methods. The paper presents a general method to derive the probability distribution of a multivariate function of random variables representing the response of a structure. The derivation is an effort to tackle the problem via the method of moment. However, a key departure is the use of fractional moments of the response function, as opposed to integer moments used so far in the literature. A new multiplicative dimensional reduction method (M-DRM) is proposed to approximate the original complex input-output relation. An efficient numerical method for fractional (integer) moment calculation was followed by using M-DRM and Gauss quadrature. The semi-analytical probability distribution of structural output is determined using the principle maximum entropy (MaxEnt) with the constraints specified in terms of fractional moments. Monte-Carlo simulation was carried out to assess the accuracy of the proposed methodology. Examples show that the results of the proposed method are fairly accurate as compared with the benchmarks by crude Monte-Carlo simulation.

GS2: Computational Mechanics

A0031- COMPUTATION APPLICATION DEVELOPMENT IN SCIENTIFIC PARADIGM

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The era in computation application development in scientific paradigm has created new opportunities for researchers to achieve high relevance, impact amid changes and transformations in how we study basic science phenomena. With the emergence of scientific paradigm collection technologies, advanced data mining and analytics support, there seems to be fundamental changes that are occurring with the research questions we can ask, and the research methods wecan apply. The contexts include social networks and blogs, political discourse, corporate announcements, digital journalism, mobile telephony, home entertainment, online gaming, financial services, online shop- ping, social advertising, and social commerce.Computing is an evolving technological paradigm that facilitates conveniently, on-demand network access to a shared pool of configurable computing resources like network, servers, storage, applications and services etc that can be presented as a service and released with minimal management effort. The model promotes availability of resources and creates powerful distributed computing system with global reach and super computing capabilities. Computing is enriching and will widen the horizon of human knowledge, empower human capital for sustainable scientific development as well as educational development of nations. This paper tries to explore the vast and immense benefits of computation development in scientific paradigm shift and its applications in e-library services in Africa today.This will allow business analysts and researchers to achieve frequent, controlled and meaningful observations of real-world phenomena. I discussed how the philosophy of science should be changing in step with the times,and illustrate our perspective with comparisons between earlier and current research inquiry in scientific paradigm.

A0063- Model Reduction Techniques for Dynamic Systems with a Large Number of Local Modes

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In a complex system with both global modes and many local elastic modes, the behavior of the local modes that are well-separated, usually has negligible effect on the global dynamics. Taking advantage of this fact, an automatic mode selection procedure is first proposed to draw a subset of dominant elastic modes in the frequency band of interest that can represent the global dynamics. This selection procedure is followed by a filtering technique that is constructed by projecting the responses of the system onto a global displacement basis, allowing enhanced accuracy in the high frequency range. Subsequently, these two methods are combined with sub-structuring techniques to allow for a computationally efficient analysis of systems with large substructures. The two reduction methods are applied to a homogeneous plate with flexible and stiff parts, a simplified nuclear fuel assembly, and a detailed boiling water reactor nuclear fuel assembly. Another application of the canister-fuel assembly model is also examined to justify combining global filtering with substructure techniques.

A0102- GROUP-THEORETIC EXPLOITATIONS OF SYMMETRY IN COMPUTATIONAL MECHANICS OF NOVEL PRESTRESSED STRUCTURES

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Symmetry is one of the most common and important features in nature. Different symmetry can be easily observed from a microscopic view to macroscopic view, from atoms and crystals to large-scale space structures. At the same time, innovative methods that consider the inherent symmetry of a system will be systematic and effective. As an important branch of mathematics and vector algebra, group theory is a powerful tool for systematic analysis on symmetric systems. It has been extensively applied in computational physics, computational chemistry, and electromagnetism. In recent years, group theory has been gradually adopted for computational problems of solid and structural mechanics. Unfortunately, group theory has not been widely adopted in computational mechanics of engineering structures because it is abstract (i.e., mathematically represented) and uncommon to most structural engineers. In addition, conventional symmetry mentioned in structural mechanics generally refers to mirror symmetry or cyclic symmetry. This paper introduces the advances made in the application of group theory in computational aspects such as stability, form-finding, natural vibration and bifurcation analysis of novel prestressed structures. As initial prestress plays an important role in prestressed structures, its contribution to structural stiffness has been considered. General group-theoretic approaches for the involved problems are presented, where certain stiffness matrices and equilibrium matrices are expressed in symmetry-adapted coordinate system and block-diagonalized neatly. Illustrative examples on structural stability analysis, force-finding analysis, and generalized eigenvalue analysis on cable domes and cable-strut structures are drawn from recent studies by the authors. It shows how group theory, through symmetry spaces for irreducible representations and matrix decompositions, enables remarkable simplifications and reductions in the computational effort to be achieved. More importantly, before any numerical computations are performed, group theory allows valuable and effective insights on the behavior or intrinsic properties of a prestressed structure to be gained.

A0188- EFFECT OF POWER TAKE-OFF DAMPING ON HYDRODYNAMIC EFFICIENCY OF AN OSCILLATING WATER COLUMN WAVE ENERGY DEVICE

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One of the simplest and most advanced technologies to harness energy from the ocean waves is the wave energy converter (WEC). A partially submerged semi-closed chamber encompasses ocean water inside the chamber with an underwater opening to the ocean. Air is trapped above the free surface inside the chamber. The incident ocean waves excite the water mass inside the chamber which goes through up and down motion with passing crests and troughs. The upward moving water column pushes the trapped air and drives it through a narrow vent. During the downward motion of the water column, a low pressure above the free surface draws air from the atmosphere through the vent. A power take-off (PTO) unit which in this case is a unidirectional Wells type air turbine is placed in the vent which is connected to a generator to generate electricity. However, the overall efficiency of these systems is still not up to the mark for commercial electricity generation. With rapid advancement in the computational facilities, Computational Fluid Dynamics (CFD) is now recognized as an important complement to traditional physical testing techniques in ocean engineering. In the present study, numerical investigation of a shore fixed OWC device is performed using CFD tool ANSYS Fluent. A multiphase volume of fluid (VOF) model is used to design a numerical wave tank (NWT) for simulation of wave generation in an ocean environment. The incident waves come from one end of the NWT and impinge on the OWC chamber placed on the opposite end of the tank. The results of wave generation are validated with the previous numerical and theoretical results. The flow characteristics inside and outside of the OWC chamber are analyzed. The damping provided by the air turbine is modeled as flow through a porous media. It replicates the pressure jump-flow behavior of a Wells-type air turbine. Both linear and non-linear models of turbine damping were considered and

simulations were carried out for different values of porous media parameters to study the turbine pressure jump characteristics. The hydrodynamic efficiency of the OWC device is calculated for different values of linear and non-linear turbine damping coefficients. The hydrodynamic efficiency is plotted against incident wave frequency for various values of turbine damping coefficients. The results were compared with the results from the previously available literature.

A0211- WEAK ENFORCEMENT OF DISPLACEMENT CONDITIONS IN FICTITIOUS DOMAIN FINITE ELEMENT ANALYSIS

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In fictitious domain finite element analysis, one of the major difficulties comes from incorporating Dirichlet boundary conditions, as the grid nodes are not guaranteed to align with the geometric boundary of the computation domain. Unlike the classical finite element method, where DBCs can be imposed node-wisely, “weak” enforcement methods are employed as alternatives. In the discontinuous Galerkin method, in which adjacent finite elements do not have shared nodes, the similar weak enforcement (more often Nitsche’s method) is also employed to weakly attach displacements between elements.Lagrange multiplier, penalty and Nitsche's methods are well-developed approaches in this area that have inspired various successors, with the recently developed linked-Lagrange multiplier and step boundary methods being two of them. Here we present a general introduction of these two methods and provide modifications with advantages. A number of numerical examples are provided to validate the accuracy of the proposed approaches, with optimal rates of convergence having been achieved.

A0290- QUANTIFICATION OF ERROR IN COMPUTATIONAL MODELS BASED ON THREE-DIMENSIONAL MICROSTRUCTURE CHARACTERIZATION

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Three-dimensional microstructures collected by experimental characterization provide both statistical information and the basis for computational models, which allows us to analyze heterogeneous materials at small length scales. However, the collection of such three-dimensional microstructural data commonly relies on destructive techniques, such as serial sectioning, and such methods often provide no quantitative measure of the accuracy of the digital microstructure in representing the true physical specimen. This makes quality assessment of the data sets difficult and it poses a challenge to identify which characterization parameters will produce optimal efficiency in the data collection process while maintaining an acceptable level of error in the resulting data. To address this question, this presentation describes a computational method that was developed to simulate serial sectioning data collection, based on a digital representation of a material, called a phantom. By simulating the data collection and data processing protocols of user defined parameters such as resolution, slice thickness, dwell time, polishing method, etc. the effect of each on error propagation can be tracked relative to the fully understood digital phantom. Then by varying each parameter the effects can be studied individually and provide bounds on both the contributions of each parameter to the error as well as the total error introduced through the experimental process. This provides a quantitative method for comparing the relative trade off between experimental parameters such collecting data at a very high resolution vs. collecting data over a large volume. Ultimately these measures are then utilized as part of an objective function to optimize the selection of experimental parameters. An example of optimization of experimental data collection parameters for the acquisition of an 3D Electron Backscatter Diffraction (EBSD) data set demonstrates how the error in computational models can be reduced.

A0629- IMPLEMENTATION OF A MESH SENSITIVE-LESS APPROACH FOR THE PSEUDO-LOWER BOUND METHOD

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In the early ages of last century, plastic methods of analysis have been introduced as solution for applications of the yield-line problem for Reinforced Concrete (RC) slabs. Such field of research has shown great potential for its application in industry. So far, several upper and lower bound methods have been proposed, but none of them have proved full reliability yet. The current research project is attempting to fill this gap and focuses on the development of an innovative Pseudo-lower bound method for the assessment of RC slabs. The obtained results have already reached a good fit with exact analytical solutions for simple cases, however the algorithm still has room for improvement. In this paper, the problem of mesh sensitivity is addressed. The method aims at providing an optimized lower bounded solution, which is reached through an iterative approach carried on with a monotonically increasing load. A yield-check is performed at each iteration within an increase of load intensity. The idea is to assess the strength of each single element individually in an automated manner, hence creating a localized yield-criterion which is dependent on the mesh size. Through such improvement, the method would not be dependent on the mesh anymore since moment capacities are adapted to the size of each single element. The outcome is a mesh sensitive-less adaptation of the Pseudo-lower bound method, which removes its dependence on the mesh, and tends to increase the accuracy of the solution, hence pushing the lower bound further up.

A0661- MECHANICAL PROPERTIES OF FILAMENTOUS NETWORKS IN TERMS OF THEIR MICROSTRUCTURE

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A randomly crosslinked polymer network forms the solid skeleton of many biological structures such as the cytoskeleton and extracellular matrix of soft tissues. The cytoskeletal network which is composed of F-actin, microtubules, intermediate filaments, binding proteins, and different cross-link filaments stabilizes the cell morphology and modulates its function such as its motility. Similarly, a network of collagen fibers forms the microstructure of the extracellular matrix and plays an important role in defining the mechanical properties of soft tissues. Thus, it is necessary to investigate the mechanical properties of random fibrous structures. In the present study, we focus on the role of the microstructure and connectivity on the mechanical properties of these networks. To this end, we use different algorithms to construct two- dimensional intertwined fibrous networks. For example, we create two dimensional fiber network structures by randomly placing fibers of a given length and orientation in a square domain. Rigid connections are defined at all points where the fibers cross and the fibers are assumed to have a bending and stretching stiffness. We then use different non-affinity measure to quantify the mechanical behavior of these networks at different length scales. We conclude that although the structure and connectivity have important roles in defining the mechanics of these networks, their effects reduce with increasing the fiber number density and the bending stiffness of the fibers.

A0700- Analytical Calculation Method for Steel Gate Wide Flange I-Shaped Deep Beam with Shear Effect of Whole Section

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Transversal section effect of shear deformation on bending normal stress is more prominent, which leading to enormous calculation error used primary beam theory in the traditional design, because the faceplate of hydraulic steel gate can be used as the flange of the main beam, and under the action of high-head, the main beam bears the nonlinear stress characteristics of short deep beams. Based on energy-variational method with shear deformation energy of whole I-beam section, through the rational selection of the longitudinal displacement function and the warping function, formulas are derived in this paper for the calculation of the deflection, bending normal stress and natural frequency. On this basis, results are compared with those obtained by various analytical methods and the finite element numerical simulation results. The results indicate that when span-depth ratio or span-width ratio is small, the bending normal stress is affected greatly by the transverse shear, and it is more significant under the concentrated load, but the shear effect reduces it when the natural frequency is calculated. Besides, compared with the existing analytical methods, the proposed method ofiers more accurate results with an extended scope of application, which can be used for the structural design.

A0983- A B-SCAN SUBSURFACE IMAGING OF GROUND CAVITIES USING AN ELASTIC WAVE FULL-WAVEFORM INVERSION METHOD

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This paper discusses characterization of ground cavities by an elastic wave full-waveform inversion (FWI) method. The elastic waves are generated by impacts on the road surface and the resulting surficial responses of the ground are inverted for the characterization of road cavities. For the simulation of elastic waves, perfectly-matched-layer (PML) is introduced as a wave-absorbing boundary, which truncates the semi-infinite domain and removes artificial reflections from the truncated boundaries. The FWI method is based on a partial-differential-equation-constrained optimization approach, which can be implemented with Karhsh-Kuhn-Tucker optimality conditions for minimizing the objective functional augmented by governing elastic wave equations via Lagrange multipliers. To alleviate the ill-posedness of the inverse problem, Tikhonov and total variation regularization schemes are used. To investigate the feasibility of the FWI method, field experiments were performed on testbed sites with an artificial cubic-shaped cavity and with a real road cavity. The cavities have been successfully reconstructed by the FWI method using ground velocities measured on the pavement surface.

GS3: Wood Mechanics

A0308- Development of An Andvanced Fe-Numerical Method for Strength Prediction of Timber Boards Based on the Surface Information

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Full 3D reconstruction of the wooden laminations is an initial step in this study for further numerical analysis. This is done based on the knot measurements on the surfaces of the boards. The aim of this study is to develop an advanced virtual method for the strength prediction of the boards. By knowing the locations of the knots, as the main strength governing parameters in timber boards, simulations are run for large quality range of wood laminations. This includes 137 low-medium quality Douglas fir, 103 medium-high quality spruce and some hardwood boards. The laminations are then used for the numerical analysis of the glulam composites. ABAQUS and PYTHON are used for the numerical simulations. An automatic link is programmed to extract the data of the database and to create the geometrical model. The 3D FE-Analyses of the geometrically reconstructed boards are successfully done in this study. Knot clusters, as multiple geometrical imperfections in timber boards are causing locallized high stresses, which may lead to the initiation of the failure in the material. Therefore, three mathematical methods are presented from the numerical simulations to calculate the stress concentration factors (SCFs) around the 3D heterogeneous defects in anisotropic wooden boards. The FEM results are used in a regression analysis to analyze the correlations with the visual measurements and to predict the tensile strength. Based on the results of the multiple regression analysis, the SCFs are much stronger strength predictors compared to the available visual grading parameters. Comparing the numerical predictions with the available machine grading methods, only the SCF values are sufficient to predict the strength of the good quality spruce boards, and equally good correlations are found between both results for the low quality Douglas fir boards. Using the dynamic modulus of elasticity as an additional parameter for the strength predictions improves the quality of the predictions significantly. The results of the current study show an improvement in the strength prediction of wood, based on the numerical simulations that are solely based on the geometrical representation of the knots.

A0955- DEFORMATION KINETICS FOR WOOD MECHANICS

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Deformation Kinetics is based on Eyring equations that describe the influence and interaction between molecules and how these interaction processes are influenced by external factors such as stress and temperature. A number of research projects have been carried out in the world using the Eyring´s ground concepts of deformation kinetics. Short and long term behaviour of wood can be described but it can also be used as a basis to describe service life behaviour of timber structures as influenced by mechanical, physical, biological and chemical degradation processes. Chemical kinetics has important advantages over standard microscale modelling in that it allows generalizations to multiple planes and scales, whereas micromechanical modelling is limited to ´perfect wood´, without the influence of grain deviations, knots etc. Therefore, microscale modelling of the microstructure of wood cells is generally described with FEM models or similar modelling techniques that needs adaption for natural wood failures as knots. Then, Monte-Carlo simulations are needed to account for spatial variations in material properties. This problem does not occur with deformation kinetics because different reaction rates at the nano-, micro-, and macrolevel are automatically accounted for. The molecular behaviour, interactions between molecules of different origin within the wood, vibration behaviour as a function of temperature and last but not least moisture cannot be easily integrated in FEM models. Application of the theory leads to various solutions for creep, stress relaxation and bond breaking, also known as damage accumulation. The damage accumulation theory can be applied on real structures, taking into account crack formation, biological degradation and mechanical loads at the same time. Model predictions can be used for risk analysis, residual load carrying capacity estimates and even maintenance planning.

A0957- AN INVESTIGATION OF THE DOL EFFECT OF WOOD´IN TENSION PERPENDICULAR TO GRAIN

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Wood is a visco-elastic material. Strength of wood decreases under long-term load (DOL effect). Currently, research of DOL effect of wood in tension perpendicular to grain is not as much as that of parallel to grain. In this study, a total of 140 Northeast China larch small clear specimens were tested under long-term tension perpendicular to grain, in which the specimens were classified into three stress levels. The short-term strength of specimens of the matched sample were also tested and compared with the long-term strength, the relationship between loading time and the strength reduction was thus obtained. It was found out that the DOL effect of tension perpendicular to grain, following a convex trend line, was less severe than that predicted by the Madison curve. Also, the test result showed that DOL of tension perpendicular to grain poses little effect on its modulus of elasticity. Four DOL models including the Foschi and Yaos' model were calibrated with the experimental data and the long-term strength was predicted by the calibrated DOL models. Finally, a refined FE model in consideration of the growth rings and creep of wood was developed based on ANSYS. Via FE simulation, the stress re-distribution was revealed and the failure mechanism of wood under long-term load explained.

A0960- AN INVESTIGATION OF FATIGUE FRACTURE OF WOOD DUE TO CYCLIC MOISTURE_INDUCED STRESS

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Moisture-induced stress in wood will occur due to moisture variations. In this study, fracture of wood due to moisture-induced stress was investigated in a point of view of the fatigue problem. Fatigue tests of wood under cyclic moisture-induced stress perpendicular to grain were conducted on small clear specimens of Scotch pine and Northeast China larch. The cracking time and cracking phenomenon of the specimens were observed and explained. A FE model was developed in corporation with ABAQUS, to simulate the moisture-induced stress in the specimen. The constitutive model was established by considering the effects of thermal expansion, viscoelastic creep and mechano-sorptive creep. The simplified Luikov heat transfer model and Fick's second law of diffusion ware employed as the governing equations for the heart and moisture transfer. The FE model was used to simulate the distribution of moisture content and moisture-induced stress under different specimen size, humidity variation period and amplitude. Moreover, a fatigue model was developed based on the DVM theory, and the fatigue prediction by the model was compared with the test results of this study. Cracking of wood due to cyclic moisture-induced stress was thus explained from a fatigue point of view.

A0968- VARIABILITY IN WOOD/PLANT ANATOMY ALONG THE SCALES

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Plants are complex composites of natural polymers. They develop from living micro cells to macro aggregates. Highly lignified plants such as gymnosperms (e.g. softwoods) and angiosperms (e.g. hardwoods, bamboo) are converted to products which are used among others in civil engineering as solids, fibres and chemicals. The micro and macro composition and shape of plants are set by genetic dispositions and reflecting the growth conditions characterized by climate, soil and external loads. A plant is a dynamic composite structure which reacts and adapts for example to wind loads, damages etc.. That results in a material with a clearly inhomogeneous composite structure. Caused by the nature of plant growth, the structure has a distinct orientation of the plant elements such as fibres, vessels and rays. For example vessels are intended to transport water from the soil via roots up to the leaves of the plant. They are oriented in vertical direction as a strongly connected 'pipe network'. In contrast rays are oriented horizontally and providing cells with water and nutrients in radial direction. These composite structures lead to anisotropic behavior of the plant elements. Most important plants for civil engineering applications are softwoods, hardwoods and bamboo. The anatomical elements are built up of organic polymers compiled to microfibrils which progress to cell walls, fibres and finally solid material (e.g. wood, bamboo). The cell wall consists of three main chemical components, cellulose, hemicellulose and lignin with polymer dimensions between 10^{-10} m and 10^{-9} m. These elements are composed to cell wall layers which forms the cell wall (thickness 10^{-6} m). The cell wall composite determines the physical and mechanical properties of the single fibre. Furthermore the orientation and the interface adhesion between the fibres define the properties of the sound solid material. It has been demonstrated that single cellulose chain molecule has a 15 times higher tensile strength than single fibre which is caused by the weak interface actions between layers. However the complexity of the anatomical elements explains the highly inhomogeneity and anisotropic behavior of the wood and the wide scatter of mechanical and physical properties within the same wood species even from the same origin.

GS4: Structural Mechanics and Simulation

A0164- HYBRID INTELLIGENCE FOR SOLVING COMPLEX ENGINEERING PROBLEMS: AN INTEGRATED HUMAN AND MACHINE LEARNING APPROACH

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This study proposes the concept of hybrid intelligence, a physics-based learning approach that integrates machine learning and physics (human intelligence), as a computationally efficient method for solving complex engineering problems. The physics-based learning encodes the underlying physics of engineering problems into machine learning models such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs) to reduce the training and simulation costs. The application of physics-based learning is demonstrated on simulating partial differential equations (PDEs) and ordinary differential equations (ODEs) in engineering systems. Firstly, a recently introduced physics-aware network known as the deep residual RNN (DR-RNN) is introduced for solving structural dynamic problems. A 10-story shear building subject to earthquake excitations is used to demonstrate the computational efficiency of the physics-based learning approach. Secondly, we introduce a FEA-Net, which is inspired by Finite Element Analysis, to solve three-dimensional (3D) heat transfer problems and demonstrate its improvements in data efficiency and memory consumption.

A0259- A PARALLEL SPECTRAL ELEMENT METHOD FOR THE SIMULATION OF SCALAR ELASTIC WAVES

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This paper discusses an explicit spectral element method for the simulation of scalar elastic waves in semi-infinite domains. To simulate the wave propagation in unbounded domains, perfectly matched layer (PML) is introduced as a wave-absorbing boundary that surrounds the finite computational domain of interest truncated from the originally semi- infinite extent. For numerical implementation of governing scalar wave equations in the PML-truncated domain, semi-discrete equations of motion are constructed by using mixed spectral elements with the Legendre-Gauss-Lobatto quadrature method, which enforces the mass matrix to be effectively diagonalized. The semi-discrete equations of motion are solved by the fourth-order Runge-Kutta method for displacement and stresses. The developed spectral element method has been applied to parallel computing based on message passing interface (MPI), which demonstrates the feasibility of the proposed method to solving large-scale elastic wave problems.

A0267- A NUMERICAL STUDY ON THE THERMO-MECHANICAL RESPONSE OF A COMPOSITE BEAM EXPOSED TO FIRE

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This paper discusses an analytical framework for estimating the thermo-mechanical behavior of a composite beam exposed to fire. The framework involves: a fire simulation from which the evolution of temperature on the structure surface is obtained; data transfer by an interface model, whereby the surface temperature is assigned to the finite element model of the structure for thermo-mechanical analysis; and nonlinear thermo-mechanical analysis for predicting the structural response under high temperatures. We use a plastic-damage model for calculating the response of concrete slabs, and propose a method to determine the stiffness degradation parameter of the plastic-damage model by a nonlinear regression of concrete cylinder test data. To validate simulation results, structural fire experiments have been performed on a real-scale steel concrete composite beam using the fire load prescribed by ASTM E119 standard fire curve. The calculated evolution of deflection at the center of the beam shows good agreement with experimental results. The local test results as well as the effective plastic strain distribution and section rotation of the composite beam at elevated temperatures are also investigated. For fire behavior simulation of the composite beam protected by fire-resisting materials, the reduction of heat transfer coefficient from the air layer to the beam is implemented. The series of numerical results demonstrates that the proposed method of structural fire analysis is suitable for predicting the fire behavior of composite beams.

A0310- Theoretical Study On Vibration Of A Simply Supported Footbridge Under Discrete Pedestrian Loading

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An analytical approach is presented to analyze pedestrian-induced vibration of a simply supported beam. In this study, discrete pedestrian loading models are proposed to simulate each footstep load induced by a pedestrian who walks or runs. The footstep loads act at different locations along the beam, depending on a step length. The loading time history of an individual footstep is determined by a different force pulse, depending on walking or running. Based on the analytical approach, relations between the beam response and the pacing parameters including a pacing period, footstep contact duration, and step length are theoretically investigated. Also, the results of vibration estimation of a simply supported beam under vertical pedestrian loading show that the proposed pedestrian-induced loading models are more reasonable than the moving load model used in current footbridge design guidelines.

A0467- IMPACT LOCATION AND LOAD IDENTIFICATION USING DEEP NEURAL NETWORKS

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Identifying the location and history of impact force applied on mechanical structures is very important for dynamic design, vibration control, reliability analysis as well as condition monitoring. Unfortunately, there are many practical situations where the direct measurement of impact forces is not easy to carry out, so many indirect identification methods, including the inverse method, the optimization method, and the neural network method, have been presented using dynamic responses typically measured by accelerometers or strain gauges. In this paper, a new identification method of impact load is proposed based on deep neural network technology. The load location is determined by a recurrent neural network (RNN) with three-layer long short-term memory (LSTM), and the impact history is evaluated by three-layer RNN model mainly including single-layer BLSTM (bidirectional LSTM) and two-layer LSTM. BLSTM layer is indispensable because it's high agreement with the physical reality of structural vibration. Only one measured point is used in our research and the predicted accuracy is not dependent on the position of accelerometers, which shows great advantage compared with other methods. Besides, some complex preprocessing, like features extraction, is not necessary for this method and signal truncation is applied for computing efficiency. The impact load identification approach is qualified through the simulated studies for a thin plate structure and different noise levels are considered. In order to counter the ill-posed problem, a data augmentation method is adopted which can identify the load with high-level noise. A GPU-accelerated library, cuDNN, is used to train the deep learning model and search for the optimal hyper-parameters. The results show that the location and history of the impact load can be identified accurately using the presented method. This approach provides an effective and feasible way for impact load identification and more engineering structures will be studied in the future, like laminated composited plates, complex nonlinear systems.

A0512- ULTIMATE CAPACITY OF BULGE FORMED T-JOINTS UNDER BRACE AXIAL COMPRESSION EXCLUDING THE CHORD LENGTH EFFECT

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An innovative stiffened tubular joint called the bulge formed joint has been developed and used in practice for the first time. Though its great advantage on the ultimate capacity had been proved by authors before, however, no parametric equation was available for the ultimate capacity prediction. In this study, the finite element (FE) method and a real scale specimen test were employed for the investigation of the ultimate capacity under the brace axial compressive loading, and only the length of joint itself was considered to avoid the overall chord length effect. Verified by the test, 27 FE models designed according to the Taguchi methodology were used to investigate effects of the geometric parameters (β, γ, τ, τs, η_1, η_2) on the ultimate capacity. Then excluding the parameter η_2 whose effect on the ultimate capacity was found negligible, 324 FE models designed based on the full factorial design approach were analyzed to derive the parametric equation for the ultimate capacity. By a large amount of the nonlinear regression analysis, the parametric equation was derived with high accuracy. The proposed parametric equation can be used for the ultimate capacity prediction for the bulge formed T-joints under brace axial compressive loading excluding the chord length effect.

A0595- EXPERIMENTAL AND NUMERICAL STUDIES OF RESONANCE VIBRATION OF CABLES IN A FOOTBRIDGE MODEL UNDER BIHARMONIC EXCITATION

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The method for reducing resonant vibrations of stay cables in a cable stayed bridge under biharmonic excitation is described; it is a new method developed by the authors. Research results indicate that resonant vibration occurring simultaneously in any two pairs of stay cables can be effectively reduced by changing static tension forces in appropriately selected stay cables. The selection of cables subjected to the change of static tension forces was performed on the basis of sensitivity analysis of eigenproblem formulated in accordance with second order theory and of linear optimization. The method was tested both on a laboratory model of a cable-stayed footbridge and on a numerical (FEM) model of a cable-stayed footbridge having geometrical and material parameters of a real bridge structure. It was found that the change in the cable tension force needed to achieve an effective level of vibration reduction does not exceed the Ultimate Load State or Serviceability Load State of the object. This statement is extremely important as it emphasizes the possibility of practical application of the proposed method of vibration reduction. The great advantage of the vibration reduction method discussed here is that there is no need to determine the causes of excessive vibration associated with excitation. The idea behind the method is to counteract the sources of the resonance phenomenon by changing the value of the structure's eigenfrequency and not the frequency of excitation. The proposed method is also effective in the case of long cables when passive and semi-active vibration eliminators mounted near the anchorage become ineffective. The proposed method can serve as an alternative to commonly applied methods of vibration reduction which use vibration dampers and eliminators.

A0721- non-linear numerical analysis on Overall process mechanical behavior of quasi-rectangular segmental tunnel lining

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A segmental tunnel lining structure with a novel type of cross-section named quasi-rectangular is utilized for the first time in Ningbo, China, as shown in Figure 1/a). The cross-section is composed of ten blocks (T1, C1, B3, B2, C3, T2, C2, B1, L and F) and an interior column (LZ). Ten blocks are connected by longitudinal joints (from No.1 joint to No.10 joint). Three full scale tests have been conducted to investigate the mechanical behavior of the structure under unexpected circumstance, such as overburden condition, where soil overburden acts on the top of the tunnel. Based on experimental results of the tests, a nonlinear finite element method is developed. The model of the structure is composed of blocks, the interior column, longitudinal joints and a rigid zone. Geometric and material nonlinearity of the included components in the elastic and plastic phases are considered. As shown in Figure 1/b), the blocks and the interior column are simulated by fiber-integration beam elements, and the longitudinal joints are simulated by beam-spring elements. The cross-section of the T block increases at its connecting part to the interior column and it is much stiffer than the neighboring segment. Therefore, it is idealized to be a rigid zone. As such, it does not deform, but it can undergo a rigid body displacement. Then comparison between the experimental and numerical results is made, paying special attention to the failure process, the deformation of the longitudinal joints and the strain of the bolts. The research has shown that: (1) the non-linear numerical model can accurately simulate the overall mechanical behavior of the structure and the mechanism of the longitudinal joints, (2) the failure mechanism of the structure begins with failure of the longitudinal joints. Finally, the structure loses bearing capacity, which is due to the fact that shear bearing failure of T block segment occurs. According to the analysis results, the failure mechanism of the structure is determined by the ultimate bearing capacity of the longitudinal joints and the segments, (3) the ideal failure mode of the quasi-rectangular segmental tunnel lining is to guarantee that failure of the longitudinal joints is earlier than failure of the segment. Therefore, the failure of the structure is characterized by ductile damage, which results in a high safety reserve of the structure under unexpected circumstances.

A0740- VIBRATION CONTROL BY NONLINEAR BOUNDARY ABSORBERS

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A nonlinearly torsional absorber assembled in the boundary is proposed for a kind of simply supported flexible structures. It not only maintains the advantage of the classic nonlinear absorber, but also has a compact structure and a certain motion space. In simple terms, the absorber absorbs the vibration energy via the rotating angle at the end of the structure. Then the energy is dissipated by the damper. The damper can be assembled between the oscillator and the ground or between the oscillator and the structure. The first one offers a nonlinear damping and doesn't appear in the boundary while the second one provides a linear damping and appears in the boundary directly. As a result, the first case has no influence on the linear character of the original structure, especially the anti-resonance, while the second case can change them. But on the other hand, the second case can restrain the vibration directly. The difficulty for the investigation to these two absorbers is how to deal with the nonlinear boundary analytically. The direct method of multiple scales, the method of mode correction and the method of harmonic balance are applied at the same time to overcome this problem. The differential quadrature element method is used to verify analytic results. Although the simulation method is more accurate than the analytic process, the analytic procedure is more effective in optimizing the absorber. Based on the investigation, we find that the energy transmits to the absorber almost unidirectional and the vibration of the structure is deduced by almost 90% of the original resonance. The nonlinearly torsional absorber in the boundary provides a new effective strategy for the vibration control.

A0903- Understanding Uncertainties from Cyclic Tests of Shape Memory Alloy Bars for Seismic Application

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Shape-memory alloys (SMAs) has the super-elasticity therefore presents promising application in vibration control of buildings and bridges subjected to seismic loads. The properties of SMA are often determined through optimization method and treated as deterministic for dynamic analysis of structures with SMA based devices. This study utilizes the Metropolis-Hasting algorithm to characterize the uncertainties in model parameters of SMA material. The probabilistic characterization presents potential correlations between model parameters, and offers insight into the uncertainty in SMA behavior under seismic excitation. A series of SMA bars with the same geometric size and heat treatment were tested. The behavior of SMA bars were studied under cyclic loads. The Markov Chain Monte Carlo (MCMC) method is applied to analyze the uncertainties of SMA in terms of model parameters, equivalent damping, and recentering capability.

GS5: Bio-Mechanics and Bone Mechanics

A0667- THE RELATION OF CORNEAL HYDRATION AND STIFFNESS IMPROVEMENT BECUASE OF THE CORNEAL CROSSLINKING TREATMENT

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Cornea is a transparent tissue that is necessary for providing clear vision and shielding the intraocular components of the eye from external damage. Keratoconus is a corneal disease which alters the microstructural organization of the collagen fibrils and subsequently damage the structural integrity of the tissue. The loss of corneal structural integrity results in its progressive thinning and assuming a conical shape because of the intraocular pressure. The corneal collagen crosslinking is a treatment procedure to halt the progression of the disease. In this procedure, collagen crosslinks are introduced inside the storma in order to strengthen the mechanical properties of the corneal tissue. The commonly used collagen crosslinking procedure is composed of soaking the tissue in the riboflavin solution and then exposing the tissue to UVA irradiation. The UVA rays damage the endothelial cells if the thickness of the cornea is less than 400 microns. Thus, it is suggested to soak the corneas in hypoosomolar solution (which causes excessive corneal swelling) in order to treat patients with thin corneas. Despite the success of this alternative crosslinking procedure, it is not yet known how it will affect its strengthening effects if an isoosmolar solution is used. In the present study, the porcine corneas were swollen to different thickness levels before crosslinking. Crosslinked corneas were then biomechanically tested to characterize their tensile strength using a DMA machine. The amount of stiffening due to the collagen crosslinking treatment was fully characterized as a function of their initial hydration. It was observed that the extent of the stiffening of the crosslinking treatment was independent of the hydration level at which the corneal samples were crosslinked when the tensile measurement was done at normal hydration levels. The experimental observations were explained by a mathematical model. The findings of the present study further supported the idea of using the modified UV corneal crosslinking in treating patients with thin keratoconic corneas.

A0870- A 3-Dimensional Modelling Comparison of the Biomechanical Stability of Lateral Lumbar Interbody Fusion with Unilateral or Bilateral Fixation Method

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In treating recalcitrant low pain or spinal deformity using interbody fusion, unilateral and bilateral fixation methods had demonstrated similar clinical efficacy. Finite-element analysis of lumbar biomechanics is performed in this study to investigate the underlying mechanisms of unilateral versus bilateral fixation. The anonymised CT scans of a human lumbar spine four and five (L4 and L5) were acquired at the Department of Orthopaedics and Traumatology, Queen Marry Hospital, the University of Hong Kong, with an isotropic spatial resolution of 1 mm. The segmentation of the CT scans was performed in 3D Slicer, an open-source platform for medical image processing, which resulted in surface triangular meshes of the two lumbar vertebrae L4 and L5, as well as their major spinal stability structures, i.e. the anterior longitudinal ligament and facet joints. A cylinder with a length of 45 mm and a diameter of 5.5 mm was built as an idealized shape of the pedicle screw implant. The screws were inserted into the lumbar vertebrae at the same positions simulating the surgery, and connected by a third cylinder representing the rod with a radius of 5.5 mm. An interbody cage, created in SolidWorks, was later placed between the bodies of the two vertebrae. Subsequently, all surface meshes (Figure 1) were converted in Geomagic Studio (3D Systems, NC, USA) into non-uniform rational basis spline (NURBS) surface patches through a series of manual procedures. The surface models were imported to COMSOL Multiphysics (COMSOL AB, Sweden), a cross-platform finite-element (FE) solver, for the analysis of the stress condition with both unilateral and bilateral fixation methods.

The 5th EMI International Conference 2019

We are pleased to invite you to the 5th EMI International Conference 2019, in Lyon, France. The topics of the conference are related to Civil and Mechanical Engineering fields with an interest on cross- and/or multi-disciplinary fields such as Material and Environmental Sciences, IT and Big Data analysis, Social impact of Natural Hazards etc.

This Conference will provide a unique opportunity for international researchers and industry experts to discuss recent results and developments in their fields of interest for mutual benefits. Approaches combining experiments, modeling and/or simulations including the influence of the boundary conditions (in situ experiments or simulations) and fabrication process are very welcome.

With an very efficient transportation system and easily connected from Foreign colleagues, the City of Gastronomy is rich in historical and cultural attractions, INSA Lyon is looking forward to welcoming you!

Ali DAOUADJI, *on behalf of the organizing team.*

What are the topics?

As for the annual EMI conferences, the EMI IC Lyon 2019 stays in line with its long-standing tradition as the prime venue for disseminating the most recent progress in Engineering Mechanics as the core discipline of science-enabled Civil Engineering and Mechanical Engineering as well. Mutual benefit are coming from cross and multi-disciplinary fields combining

Conference venue

Lyon Tech La Doua Campus and INSA Lyon's facilities will welcome you during your stay. There are numerous hotels downtown in Lyon located in very beautiful neighbourhoods and in Villeurbanne too.

Good access to the airports of Lyon Saint-Exupéry and Paris - Charles de Gaulle and Paris - Orly, as well as to the central station using high speed trains TGV, is provided. Take the Tramways T1 or T4 and you will reach the Campus.

Who are the organizers?

EMI International Conference is organized under the auspices of Engineering Mechanics Institute (EMI) which is a Department of the American Society of Civil Engineers (ASCE). The Local and International Scientific Committees are given in the Website (emilyon2019.sciencesconf.org)

We'll keep you informed.

All information concerning the conference venue, lodging, registration, fees, mini-symposia and abstract submission and the program will be provided soon on the conference website emilyon2019.sciencesconf.org. Feel free to pass this announcement to anyone who might be interested.

See you in Lyon next July!

Dates & deadlines

15 September 2018	Mini-Symposium submission opens
1 October 2018	Conference registration opens
1 December 2018	Abstract submission opens
28 February 2019	Abstract submission closes
1 April 2019	Notification to authors on acceptance
2 July 2019	Arrival & registration, Icebreaker evening
3 - 5 July 2019	EMI International Conference Lyon

EMI IC Lyon 2019

EMI 2019

Engineering Mechanics Institute Conference
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2. Multiscale and Multiphysics
3. Geomechanics and Geomaterials
4. Probabilistic Mechanics and SHM
5. Multihazards
6. Biomaterials and bio-inspired engineering
7. Flow and Phase transitions
8. Awards and celebrations
9. Damage, bifurcation, and fracture
10. Mechanics of Materials and Material Science

Conference Dates & Location

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- Zdeněk P. Bažant Medal for Failure & Damage Prevention
- Maurice A. Biot Medal
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- Alfred M. Freudenthal Medal
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Program At A Glance

November 2th, Friday	
14:00--21:30	Registration (The 3rd floor of Kingswell Hotel VIP Room)
19:00--21:00	Ice Breaker Reception
November 3th, Saturday	
8:00--18:00	Registration (Sino-French Center Room C201)
8:30--8:50	Welcoming Remarks
8:50--9:00	Group Photo
9:00--10:20	Plenary Lectures
9:00--9:40	Prof. Zdeněk P. Bažant Lecture title: Design of New Materials and Structures to Maximize Strength at Probability Tail: A Neglected Challenge for Quasibrittle and Biomimetic Materials
9:40--10:20	Prof. Hai-Yan Hu Lecture title: Engineering Dynamics of Soft Machines
10:20--10:40	Coffee Break
10:40--12:10	Technical sessions
12:20--13:30	Lunch
14:00--14:40	Plenary Lecture
	Prof. Jin-Guang Teng Lecture title: Mechanics of interfaces in FRP-strengthened structures
14:50--15:50	Technical sessions
15:50--16:10	Coffee Break
16:10--17:55	Technical sessions
18:30--21:00	Banquet
November 4th, Sunday	
8:30--9:50	Plenary Lectures
8:30--9:10	Prof. Herbert Mang Lecture title: Multiscale Analysis of Concrete Structures A Joint Research Project of Tongji University and Vienna University of Technology
9:10--9:50	Prof. Lori Graham-Brady Lecture title: Uncertainty propagation from materials characterization to modeling
9:50--10:10	Coffee Break
10:10--12:10	Technical sessions
12:20--13:30	Lunch
14:00--14:40	Plenary Lecture
	Prof. Jiun-Shyan (JS) Chen Lecture title: Meshfree Methods: Progress Made After 20 Years and Future Directions
14:50--16:05	Technical sessions
16:05--16:25	Coffee Brea
16:25--18:10	Technical sessions