Editorial

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Biographical notes: Brian M. Phillips is an Associate Professor in the Department of Civil and Coastal Engineering at University of Florida. He received his BS in Civil Engineering from the University of Pittsburgh and MS and PhD in Civil Engineering from University of Illinois. His research areas include structural dynamics, structural control, optimisation, protective systems, wind engineering, and earthquake engineering. His research aims to deliver resilient and sustainable infrastructure through technological advances and the integration of cyber and physical systems.

Wei Song is an Associate Professor in the Department of Civil, Construction and Environmental Engineering at The University of Alabama. He holds a BS and a MS in Civil Engineering from Tongji University, another MS in Systems Science and Mathematics from Washington University in St. Louis, and PhD in Civil Engineering from Purdue University. His research is mainly in the areas of structural dynamics and structural condition assessment. He is interested in developing novel tools, including new damping system, hybrid simulation, and machine learning, to solve problems in the above areas.

Shirley J. Dyke is a Professor of Mechanical Engineering and Professor of Civil Engineering at Purdue University. She is the Executive Director of the Resilient Extra-terrestrial Habitats Institute and the Director of the Intelligent Infrastructure Systems Lab. She is the PI of the Multi-Hazard Engineering Collaboratory for Hybrid Simulation, an NSF-funded Research Coordination Network focused on broadening the community of researchers that are engaged in hybrid simulation. Her research focuses on the development and implementation of 'intelligent' structures, and her innovations encompass structural control technologies, structural health monitoring, real-time hybrid simulation, and machine learning and computer vision for structural damage assessment.

1 Introduction

Hybrid simulation (and real-time hybrid simulation, RTHS) is a powerful technique that integrates physical experimentation with computational simulation to observe and evaluate complex engineering systems. This coupling of a physical subsystem with a computational subsystem enables a detailed examination of the complete system while imposing realistic conditions on the selected physical subsystem. Hybrid simulation is mainly used either when a structural system is either too large or too complex to evaluate using traditional techniques (high-rise buildings and long-span bridges, for example), or when the response of a physical specimen cannot be predicted using the latest computational models and its behaviour must be observed under realistic operational conditions. In this way, researchers and practitioners can gain a better understanding of complex structural systems, potentially leading to improved computational models. Thus, hybrid simulation provides a critical bridge towards advancing and expanding our capabilities in computational modelling.

The majority of past hybrid simulation development and applications have been in earthquake engineering. However, there is great potential to tackle a much broader set of problems by expanding the scope and capabilities of hybrid simulation to multi-hazard engineering. This special issue focuses on advances taking place around the world that are essential for both establishing the fundamental theory and demonstrating the potential for hybrid simulation methods in multi-hazard applications. It includes eight articles that span the following topics:

1 developments in enabling technologies

2 innovative multi-hazard applications

3 uncertainty quantification and reliability analyses.

1.1 Developments in enabling technologies

Hybrid simulation was established to study the dynamic response of structures under earthquake loads using traditional numerical integration techniques and conventional actuator systems. These technologies may not be suitable for all applications, in particular when considering different hazards. Forouzan et al. recognises that conventional hybrid simulation does not strictly ensure force equilibrium. The authors propose the concept of force-based hybrid simulation to eliminate unbalanced forces, leading to consistency between motion-induced forces and structural deformation. This consistency is particularly important when considering aerodynamic and hydrodynamic loading. Additionally, traditional numerical integration techniques can create stability and quantisation problems, in particular for RTHS. Harris and Christenson address these issues through an analogue circuit approach to solving the equations of motion. This approach can readily implement high-frequency dynamics that may be challenging for traditional approaches to RTHS. Ghaffary et al. investigate the potential for RTHS in the field of wind engineering. Suitable hardware, software, and transfer systems are proposed, which are built on traditional boundary layer wind tunnel testing to open the door to new applications of hybrid simulation. In earthquake engineering, shake tables are a traditional tool used for the dynamic analysis of structural behaviour. Vega et al. investigates the use of a shake table as the transfer system in RTHS. Shake table RTHS only requires key subassemblies to be experimentally modelled on the shake table while the remainder of the structure is simulated numerically. A series of demonstration tests were performed on the University of California, San Diego's large outdoor shake table.

1.2 Innovative multi-hazard applications

Hybrid simulation is already seeing applications in multi-hazard investigations. Kolay et al. applies RTHS to study the dynamic response of a 40-storey tall building outfitted with nonlinear fluid viscous dampers. The building frame is modelled numerically and the dampers are modelled physically. The authors investigate both seismic and wind loading on the system, a step toward applies RTHS in performance-based engineering considering multiple hazards. Tian et al. applies shake table RTHS to investigate the multiple hazards that can threaten wind turbines at various stages in their construction. A tuned mass damper is proposed and evaluated to mitigate responses to seismic and wind loads, including vortex-induced resonance, a step toward implementing wind turbines in complex working environments.

1.3 Uncertainty quantification and reliability analyses

Uncertainties in the dynamic behaviour of structural components are not traditionally considered through hybrid simulation approaches. However, these uncertainties are critical when investigating risk and reliability. Ligeikis and Christenson propose linking Kriging metamodelling, an adaptive learning algorithm, Monte Carlo simulation, and RTHS to iteratively estimate the failure probability of a structural system. The authors were able to accurately predict failure for a system with up to 24 randomised parameters in the numerical model while limiting RTHS experiments to a reasonable number. Wu et al. proposes the integration of RTHS into a quantitative assessment of seismic resilience. RTHS and experimental component metamodelling were combined to efficiently develop fragility curves to support resilience assessment.