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# Preface: Advances in OpenSees Applications to Civil Engineering

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This special issue is dedicated to the memory of a world-renowned expert in earthquake engineering, Professor Stephen A. Mahin (October 16, 1946 - February 10, 2018), for his educational efforts and visionary research contributions that spanned theory, numerical modeling, computer simulation, laboratory experiments, field testing, and design code development. His decades of prolific, enthusiastic, and selfless service to the academia, profession and industry as well as his friendship will be remembered forever. In his capacity as the Director of the Pacific Earthquake Engineering Research (PEER) Center (2009-2015), Professor Mahin was steadfast in supporting the development and application of *OpenSees* (i.e., Open System for Earthquake Engineering Simulation). To recognize his great efforts, this special issue is about the applications of OpenSees in civil engineering, and *Computer Modeling in Engineering & Sciences* (CMES) is a suitable journal for this special issue.

*OpenSees* is an open source object-oriented finite element (FE) software framework for modeling structural and geotechnical systems subject to static or dynamic loads, with a particular emphasis on earthquake engineering. This computational software framework has been developed since 1997 under the umbrella of the PEER Center mainly funded by the National Science Foundation (NSF). *OpenSees* supports a wide range of simulation purposes, solution procedures, distributed computing capabilities, and high-end computing services. For example, it allows the integration of advanced models of structures and soils to investigate challenging soil-foundation-structure interaction problems. Specifically, it has very attractive capabilities for model parameterization, response sensitivity analysis, probabilistic modeling, and reliability analysis. As an open-source FE software framework, *OpenSees* has continuously integrated the latest research outcomes (e.g., finite element and material models, numerical solution strategies, computing technologies) from researchers and engineers across the world. As such, *OpenSees* has become one of the most powerful open-source research and development tools, through which users can implement and test new ideas and concepts more easily and faster than before. With this background in mind, this special issue mainly focuses on, but not limited to, the sustained developments and wide-spread applications of *OpenSees* in the civil engineering. The work collected in this

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special issue is briefly summarized below.

Li et al. [Li, Conte and Gill (2019)] proposed a probabilistic performance-based optimum seismic design (PPBOSD) framework to assist in designing structures that explicitly satisfy probabilistic performance criteria. PPBOSD was implemented by wrapping a design decision-making layer around the forward performance-based earthquake engineering (PBEE) analysis method. This extended PBEE framework could be used to develop, calibrate and validate simplified probabilistic performance-based design procedures. Ribeiro et al. [Ribeiro, Barbosa and Neves (2019)] studied the probabilistic performance of the 3- and 9-story pre-Northridge SAC buildings in Los Angeles considering ductile and brittle beam-column connection failures. This study investigated, using *OpenSees*, the influence of the uncertainty associated with connections brittle fracture on building interstory deformation capacity, as well as its impact on the bias and variability of fragility functions and loss assessment.

Lu et al. [Lu, Tian, Sun et al. (2019)] developed a high-performance triangular shell element (i.e., NLDKGT) and an explicit algorithm (i.e., the leapfrog integration method) in *OpenSees* to solve problems with complicated boundary conditions and strong nonlinearity. The stability and efficiency of the proposed shell element and explicit algorithm were validated through their application to the nonlinear seismic response analysis of a high-rise reinforced-concrete building. Sun et al. [Sun, Li, Gu et al. (2019)] proposed a method to couple peridynamic (PD) theory with the a numerical substructure method (NSM) for modeling structures with local discontinuities, taking advantage of the powerful capabilities of PD in simulating discontinuities and the high computational efficiency of NSM. Gu et al. [Gu, Wang and Huang (2019)] proposed a method to integrate PD theory and OpenSees by using a Client-Server (CS) software integration technique, such that PD could directly use the material constitutive models available in *OpenSees*. The integrated *PD-OpenSees* platform was capable to solve a wide range of complex problems in civil engineering.

Zhou et al. [Zhou and Chen (2019)] proposed a novel numerical simulation approach for a three-dimensional (3D) isolation system designed for a facility with a large aspect ratio. A numerical model for simulating the vertical quasi-zero stiffness (QZS) isolation system was developed and combined with the rubber isolator element to model the 3D isolation system. The model was implemented into *OpenSees* and used to investigate the seismic response of the isolated facility under earthquake excitations and impact. Guo et al. [Guo, Zeng, Gou et al. (2019)] developed nonlinear models of a high-speed rail bridge with CRTS-II slab ballastless track system to simulate its seismic response, with a special attention to the rotational friction dampers (RFD).

Liu et al. [Liu, Zheng, Tang et al. (2019)] derived and extended a high-order doubly asymptotic transmitting boundary (DATB) to simulate the interaction between an underground station and the surrounding layered soil medium in the context of the finite element method. The stability, accuracy and efficiency of the proposed method showed that it was suitable for seismic response analysis of underground station-layered soil interaction systems. Qiu et al. [Qiu, Lu, Elgamal et al. (2019)] presented recent research on numerical simulation and PBEE analysis of ground-foundation-structural systems using advanced material modeling techniques and high-performance computing resources, together with graphical user interface tools enabling routine usage of such advanced 3D simulation tools. Salami et al. [Salami, Dizaj and Kashani (2019)] proposed a nonlinear FE modeling technique of rectangular and circular reinforced concrete (RC) columns, which included various features of cyclic degradation (e.g., inelastic buckling and low-cycle fatigue) and was able to capture key failure modes of such columns under dynamic loadings. This modeling technique was then used to investigate the seismic performance of RC columns under biaxial multiple (main shock and aftershocks) seismic excitations. Mohammed and Barbosa [Mohammed and Barbosa (2019)] proposed a three-dimensional nonlinear modeling strategy to simulate the seismic responses of slender reinforced concrete structural walls. The buckling and low-cyclic fatigue effects were considered in the uniaxial model for the longitudinal steel bars. Experimental case studies of reinforced concrete walls with rectangular-shape, T-shape, and U-shape cross-sections were used to validate the modeling strategy.

Schellenberg et al. [Schellenberg, Huang and Mahin (2019)] presented a versatile and computationally efficient method for coupling several finite element analysis (FEA) programs, by adding generic and adapter elements, to simulate the static or dynamic response of a complete system. *OpenFresco* (Open-source Framework for Experimental Setup and Control) was used for concurrent and continuous data exchange, in a modular and synchronized manner, between all the coupled FEA codes. Sarebanha et al. [Sarebanha, Schellenberg, Schoettler et al. (2019)] described the adaptation of a full-scale bearing test machine for real-time hybrid simulation of large scale dynamic tests. Using a new model for inertia and friction force correction and high performance parallel computing, the real-time hybrid testing method was capable to experimentally simulate the behavior of full scale isolators and capture interactions between the numerical models of the superstructure and physical specimens of the isolators.

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