Special Issue on Real-time Hybrid Simulation

Preface

Real-time Hybrid Simulation (RTHS) is increasingly being recognized as a powerful emerging technique that offers the opportunity for global system evaluation of civil infrastructure systems subject to extreme dynamic loading. In this approach a *physical* portion of the structural system (e.g., a bridge column) is tested, while components of the structure that are well understood may be replaced with a *computational* model. This approach offers an alternative or enhancement to traditional shake table testing to evaluate global responses for earthquake inputs. Thus, it facilitates testing of larger and more complex structures. Clearly, advances in the field of RTHS are enabling more cost-effective and efficient evaluations of new structural systems under realistic conditions.

Although conceptually very attractive, research and development is needed to identify, analyze, and meet the challenges associated with the use of RTHS. For instance, the dynamics associated with actuators and controllers require understanding, new integration schemes are needed to meet strict time constraints, and communication/computation delays are typically present in the closed loop system. Thus, progress in this cutting-edge and highly interdisciplinary research field requires a variety of knowledge from structural engineering, computational mechanics, control theory, physics-based and phenomenological modeling, real-time computing, embedded systems, sensors and actuators, system modeling, etc.

This *Special Issue on RTHS* has been organized as a result of the compelling need for communicating the state-of-the-art regarding RTHS to the research community. The collection of articles contained herein is dedicated to improving our understanding of and ability to take advantage of RTHS methods. The issue contains several examples of novel research efforts that have been enabled through the use of these powerful techniques. Bursi et al conduct research on the performance of industrial piping systems; performance evaluation is enabled with the RTHS method. Shao et al validates the use of RTHS in testing a wood-frame structure with rate-dependent, viscous devices to establish design procedures for such systems. Nakata and Stehman present a suite of techniques to enable reliable sub-structure testing with a shake table. Experimental validation is demonstrated using RTHS of a ten-story steel structure. Phillips proposes a new actuator control algorithm that accounts for the actuator dynamics and experimental validation is performed through application on a controlled nine-story building. And Wu and Wang develop an innovative approach to identify the parameters of a model of a specimen for RTHS.

Advances in RTHS are also benefitting from the development or use of specialized hardware. Igarashi introduces and validates a new circuit designed specifically for real-time execution of the integration of the equations of motion. Ashasi-Sorkhabi and Mercan developed and demonstrated a versatile, reconfigurable platform for RTHS.

Recent efforts to illuminate the fundamental challenges in RTHS will also ensure that we are better able to plan and assess experiments that utilize RTHS. Marisco conducted an experiment using RTHS of a cable-stayed bridge, using a cable as the physical portion of the test. She identified the presence of specific delays and dynamics in the closed loop system, and noted the challenges regarding stability. Chen et al proposes a new frequency-domain method for post-experiment assessment of the tracking errors in a RTHS, considering both the amplitude and phase errors. Maghareh et al models the complex actuator dynamics as a delay, and uses the idealized model to propose a criterion for pre-experiment planning and design of a RTHS test to achieve stable execution. Wang et al. develops a method for online estimation of the lags present in the closed loop system, and applies this to perform RTHS of a buckling-restrained brace specimen. Zhu et al. proposes an explicit displacement prediction scheme for accommodating large integration steps, and validated the use of this method through simulations and experiments.

Further understanding and adoption of RTHS will be accelerated through access to key data from actual experiments. Many of the authors contributing to this special have published their data on the NEEShub (nees.org), a public collaboration platform developed for earthquake engineering research. The availability of this valuable data allows researchers and educators to learn from their experiences, and facilitates direct re-use of the data for the generation of new knowledge. For instance, Nakata and Stehman have published data from the experiments employing the suite of methods proposed, which will enable new users to more quickly understand and adopt these techniques in their own labs. Chen et al employ the data published from prior experiments conducted using the NEES network. He reuses these data to demonstrate the use of the proposed assessment technique. Shao cites the published data from the NEES-Soft project on the tracking performance when RTHS is applied to a rate-dependent experiment involving a wood-frame structural specimen. Phillips published data that validates application of a newly developed control method to perform RTHS using a controlled, 9-story building. Maghareh also published the data from the experiments performed to illustrate the use of the stability switch criterion for planning RTHS. A variety of other sources of data from actual RTHS experiments is also available on the NEEShub.

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