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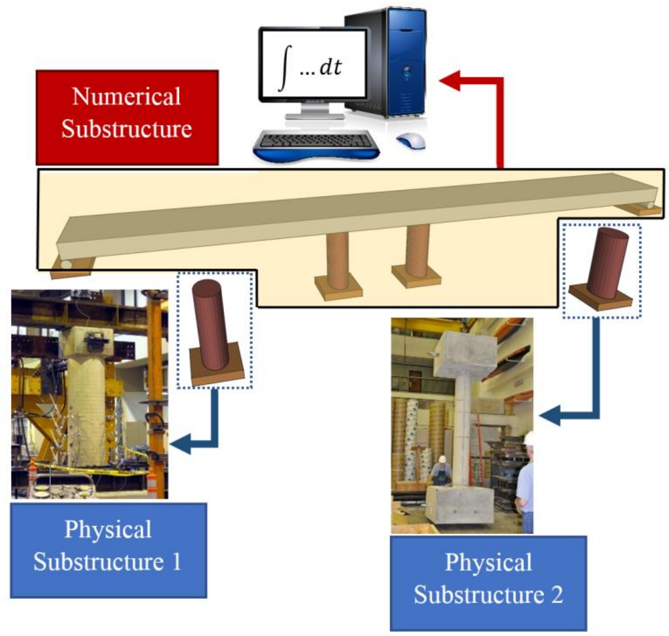
SeismicWaves

How the National Earthquake Hazards Reduction Program Is Advancing Earthquake Safety

When (Physical + Numerical = Testable System)

NEES-Enabled Advances in Hybrid Simulation

As the utility of hybrid simulation (HS) has grown over the past decade, NEHRP has led the development of this innovative research method. HS combines physical experimentation with computational simulation[1] to examine how structures and lifelines respond to simulated earthquakes and thus, how they are likely to respond in actual earthquakes.



Impetus for Hybrid Simulation

The desire of stakeholders to consider potential consequences as well as safety when judging alternative seismic design or retrofit plans for their structures has driven the development of performance-based earthquake engineering (PBEE). Use of PBEE, in turn, depends upon the ability to accurately assess the seismic performance of alternative designs. Physically testing the performance of entire buildings or infrastructure systems in laboratories can be impractical due to the scale or costs involved. However, laboratories can generally accommodate testing of critical or previously untested components of structures, while recent advances in modeling and high-performance computing have made it increasingly feasible to obtain high fidelity responses of a structure's noncritical or well understood components through numerical simulation.

All of this has boosted the potential utility of HS technologies, which link physical and numerical simulation across time and space. During HS tests, the physical responses of laboratory specimens interact with the modeled behavior of other system components to reveal how an entire system performs in an earthquake.

HS methods may be categorized by the speed at which they are implemented. Conventional HS are structured as a series of discrete steps, each comprising physical or modeled seismic inputs followed by measured or computed responses (with the responses looped into the next step). In this type of HS, time is stretched out compared to real-time hybrid simulation (RTHS), a newer, faster form of HS that executes the test at the actual speed of the earthquake input by using embedded systems with real-time computing capabilities to communicate among experimental and computational resources. If rate dependencies play a role in the system or behavior being examined, RTHS methods are more appropriate than conventional HS.

Role of NEHRP in HS Development

Through its participation in NEHRP, the National Science Foundation (NSF) has served as a preeminent catalyst for advances in HS. NSF has accomplished this chiefly through its decade-long support for the creation, operation, and use of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). This network includes many of the nation's most advanced, university-based earthquake engineering experimental facilities, linked by a state-of-the-art cyberinfrastructure that hosts simulation software, a repository for simulation data, and related educational resources. Its combination of physical and computational simulation tools has made NEES a natural locus for the development of HS.

With the support provided by NSF, several NEES experimental sites have pioneered advances in HS. For

[1] Mathematical representation of relevant physical behavior, through which responses to seismic inputs are determined via computer software; also known as numerical simulation or computational modeling.

example, the NEES Multi-Axial Full Scale Sub-Structured Testing and Simulation (MUST-SIM) facility at the University of Illinois at Urbana-Champaign has developed unique experimental equipment and software that allows the researcher to apply combinations of loads and boundary conditions on large-scale specimens. The open source Simulation Coordinator (SIMCOR) software is capable of integrating multiple, geographically distributed experimental and computational resources in HS tests. Another prominent software tool for HS is the Open-source Framework for Experimental Setup and Control (OpenFresco) software featured at the NEES facility at the University of California, Berkeley (UCB). The reconfigurable reaction-wall facility at Berkeley combined with a versatile array of hydraulic actuators allow for novel testing of a wide variety of structural and nonstructural systems. The NEES Real Time Multi-Directional Testing (RTMD) facility at Lehigh University specializes in RTHS for earthquake simulation of large-scale structural systems. The equipment available at the RTMD facility offers unparalleled speed for meeting the needs of the research community in real-time actuation. Up to five hydraulic actuators may be used in a variety of arrangements to perform a multitude of tests. The NEES facility at the University at Buffalo also features capabilities to perform HS and RTHS tests, potentially using their large-scale shake table array and nonstructural testing facility.

NSF has supported this work, not only through operation of NEES, but also through the numerous grants it has awarded to competing researchers under its annual NEES Research (NEESR) solicitations. Researchers have used HS and RTHS methods to verify a variety of design concepts intended to lessen earthquake risk in the built-environment. Some of these include evaluation of a new design methodology for precast concrete floor systems, performance-based design procedures for buildings with various damping systems, innovative structural systems and energy dissipating concrete infill panels for steel-framed buildings, investigations of the collapse mechanism in building structures, design alternatives for electrical disconnect switches and design implications for bridge systems subjected to complex ground motions. Furthermore, a significant portion of researchers' efforts have recently focused largely on advancing RTHS. For instance, efforts include the development and validation of algorithms that compensate for the inherent dynamics of test components, that support communication and synchronization when performing a test across multiple sites, and that exploit the power of parallel and multi-stepping methods for execution of the computational components.

The NEEScomm headquarters at Purdue University, which manages NEES operations, has coordinated the network's efforts to advance HS capabilities. A 2011 report[2] prepared by a committee of leading researchers provided guidance on what can be done by NEHRP through NSF and NEES to continue the development of HS technologies. In 2013, NEEScomm surveyed the international earthquake engineering community about how NEES can best facilitate access to, use of, and further development of HS and RTHS technologies.[3] Subsequently, a HS workshop was held by NEEScomm at the network's annual meeting in August 2013.[4] NEES will employ the resulting set of user requirements to continue its support for HS by focusing on broadening the user base, providing examples and user guides, increasing awareness about the potential of HS technologies, developing measures that assess the performance of these techniques, and establishing standards for interoperability among HS tools.

Links to HS/RTHS-related resources are available at http://nees.org/topics/RTHSwiki.

[2] NEES Subcommittee on Simulation, *NEES 2011 Vision Report on Computational and Hybrid Simulation: Needs and Opportunities*, October 31, 2011, http://nees.org/resources/3834.

[3] Report on the hybrid simulation survey is available at: http://nees.org/announcements/results-for-hybrid-simulation-survey

[4] Report on the hybrid simulation workshop is available at: http://nees.org/resources/7154