Simulations aiding study of earthquake dampers for structures

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Earthquake-engineering researchers at the Harbin Institute of Technology in China work to set up a structure on a shake table for experiments to study the effects of earthquakes. Purdue University civil engineering students are working with counterparts at the institute to study the reliability of models for testing a type of powerful damping system that might be installed in buildings and bridges to reduce structural damage and injuries during earthquakes. Credit: Harbin Institute of Technology

Researchers have demonstrated the reliability and efficiency of "real-time hybrid simulation" for testing a type of powerful damping system that might be installed in buildings and bridges to reduce structural damage and injuries during earthquakes.

The magnetorheological-fluid dampers are shock-absorbing devices containing a liquid that becomes far more viscous when a magnetic field is applied.

"It normally feels like a thick fluid, but when you apply a magnetic field it transforms into a peanut-butter consistency, which makes it generate larger forces when pushed through a small orifice," said Shirley Dyke, a professor of mechanical engineering and civil engineering at Purdue University.

This dramatic increase in viscosity enables the devices to exert powerful forces and to modify a building's stiffness in response to motion during an earthquake. The magnetorheological-fluid dampers, or MR dampers, have seen limited commercial use and are not yet being used routinely in structures.

Research led by Dyke and doctoral students Gaby Ou and Ali Ozdagli has now shown real-time hybrid simulations are reliable in studying the dampers. The research is affiliated with the National Science Foundation's George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES), a shared network of laboratories based at Purdue.

Dyke and her students are working with researchers at the Harbin Institute of Technology in China, home to one of only a few large-scale shake-table facilities in the world.

Findings will be discussed during the NEES Quake Summit 2013 on Aug. 7 and 8 in Reno. A research paper also was presented in May during a meeting in Italy related to a consortium called SERIES (Seismic Engineering Research Infrastructures for European Synergies). The paper was authored by Ou, Dyke, Ozdagli, and researchers Bin Wu and Bo Li from the Harbin Institute.

"The results indicate that the real-time hybrid simulation concept can be considered as a reliable and efficient testing method," Ou said.

The simulations are referred to as hybrid because they combine computational models with data from physical tests.

"You have physical models and computational models being combined for one test," Dyke said.

Researchers are able to perform structural tests at slow speed, but testing in real-time – or the actual speed of an earthquake – sheds new light on how the MR dampers perform in structures. The real-time ability has only recently become feasible due to technological advances in computing.

"Sometimes real-time testing is necessary, and that's where we focus our efforts," said Dyke, who organized a workshop on the subject to be held during the NEES meeting in Reno. "This hybrid approach is taking off lately. People are getting very excited about it."

Ozdagli also is presenting related findings next week during the 2013 Conference of the ASCE Engineering Mechanics Institute in Evanston, Ill.

The simulations can be performed in conjunction with research using full-scale building tests. However, there are very few large-scale facilities in the world, and the testing is time-consuming and expensive.

"The real-time hybrid simulations allow you to do many tests to prepare for the one test using a full-scale facility," Dyke said. "The nice thing is that you can change the numerical model any way you want. You can make it a four-story structure one day and the next day it's a 10-story structure. You can test an unlimited number of cases with a single physical setup."

The researchers will present two abstracts during the Reno meeting. One focuses on how the simulation method has been improved and the other describes the overall validation of real-time hybrid simulations.

To prove the reliability of the approach the researchers are comparing pure computational models, pure physical shake-table tests and then the real-time hybrid simulation. Research results from this three-way comparison are demonstrating that the hybrid simulations are accurate.

Ou has developed a mathematical approach to cancel out "noise" that makes it difficult to use testing data. She combined mathematical tools for a new "integrated control strategy" for the hybrid simulation.

"She found that by integrating several techniques in the right mix you can get better performance than in prior tests," Dyke said.

The researchers have validated the simulations.

"It's a viable method that can be used by other researchers for many different purposes and in many different laboratories," Dyke said.

More information: Application of Robust Integrated Actuator Control Strategy in Real Time Hybrid Simulation, Presenter: Ge(Gaby)Ou, Purdue University

Abstract

Real-Time Hybrid Simulation performs substructure test in real-time scale and includes rate dependent feature in consideration. One major challenge for RTHS is that it requires accurate and prompt execution of boundary condition that is calculated from numerical substructure. In most cases, traditional PID control induces large time lag between desired command and response which may cause system instability and further the failure of the test. Many control strategies for servo hydraulic actuator-structure system have been proposed recently to compensate such time lag and other system dynamics. This presentation introduces a new integrated control strategy into RTHS. The new proposed algorithm integrates three key control components; first, a loop shaping feedback control based on H-âˆž optimization, second the Kalman filter for feedback estimation and a pure delay feed-forward block for control performance enhancement. The combination of the aforementioned blocks provides flexible performance according to different control evaluation criterion. RIAC has been applied for displacement tracking through RTHS of a 3DOF steel structure with equipped magnetorheological (MR) damper located in Harbin, China. The experimental components herein is the MR damper attached to a large scale actuator has maximum force capacity of 2000N, the numerical substructure is the rest of the steel structure.

Comparison of shake table test with real time hybrid simulations for a large-scale, Presenter: Ali Ozdagli, School of Civil Engineering, Purdue University

Abstract

Real-time Hybrid Simulation (RTHS) enables physical testing of critical sub-structural elements in a cost-effective way, compared to other existing test methods such as shake-table or pseudo-dynamic testing. As RTHS methodologies develop, there is still a pressing need to assure growing interest from the civil engineering community seeking validation. To meet community expectations and reveal the feasibility of

RTHS, an international multi-university research project has been proposed focusing on verification of RTHS with shake table tests. The development and implementation of the comparison tests comprise the following tasks: (1) a 3.6 meters tall three story 3-D steel frame structure with base plan dimension of 1.84 m by 2.04 m - located in Structural and Seismic Test Center at Harbin Institute of Technology, China - was selected to be tested on the shake table; (2) a 2500 N capacity magneto-rheological (MR) fluid damper was attached to the first floor of the frame as the main energy dissipation device; (3) the integrated system was tested on the shake table under various earthquake inputs, and analytical simulations were developed for the comparison basis; (4) for the RTHS scheme, the system was divided into physical and numerical components. The steel structure was modeled as the numerical substructure whereas the MR damper was chosen as the physical component as it allows test repeatability without compromising system integrity. A 2500 kN capacity actuator is used as the transfer interface between physical and numerical substructure. Accuracy of numerical models, performance of MR damper controllers and data quality of RTHS are evaluated through comparisons with shake table structural responses. The results indicate that the RTHS concept can be considered as a reliable and efficient testing method.

Provided by Purdue University