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Real-Time Hybrid Simulation of Complex Structures Subject to Strong Earthquake Shaking

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Abstract

While experimental facilities are being built around the world that will substantially increase the ability of earthquake engineers to understand the complex, often nonlinear behavior of constructed facilities and soil deposits subjected to strong earthquake ground shaking, the size, weight and complexity of modern structures makes it difficult in the laboratory fully assess their seismic performance. However, modern design approaches often seek to achieve systems that concentrated damage, if it occurs, in a few carefully detailed structural elements, or in manufactured devices. Thus, many large systems may be idealized as a few discrete locations that exhibit complex nonlinear behavior, and other regions that are expected to respond in a well understood and essentially elastic manner. For such systems, hybrid simulation methods used in conjunction with modern experimental facilities may permit experimental verification of the behavior of large systems that cannot be tested by other means.

Hybrid simulation is a relatively mature technology with its origins in the 1970s. However, recently it has been applied to a widening sphere of applications. In this presentation, three types of rapid- or real-time hybrid simulation are described. These are:

1. Geographically distributed hybrid testing. – Often specialized testing equipment exist at various laboratories that are geographically separated. In this case, hybrid simulation, implemented using modern hybrid simulation implement software, like OpenFRESCO, enables an integrated test where portions of the overall model are numerically analyzed, and the other parts are tested at laboratories having the appropriate equipment. As such, geographically

distributed hybrid simulation may provide an effective means for unusually large or complex structural systems to be tested using specialized test equipment at the existing NCREE facilities in Taipei and new ones being developed in Southern Taiwan. Examples of real and rapid geographically distributed hybrid tests of bridges and buildings will be presented.

2. Hybrid tests using multi-axis test system (MATS). – The NCREE lab in Taipei incorporates a large and capable MATS machine. In many systems, like seismically isolated structures, or structures with specialized rocking or self-centering structural walls, it is expected that inelastic behavior is localized. However, it is desired to test the inelastic portions of the system in as realistic of scale as possible. In such circumstances, it is possible to test full- or large-scale isolators or other critical components using the MATS machine, and to numerically model the remaining portions of the structure. Examples of recent fast tests of this type will be presented. In these experiments, full scale seismic isolators are tested for situations where they support critical nuclear facilities, bridge superstructures, and buildings.
3. Hybrid or smart shaking tables. – Considerable interest exists in hybridizing shaking tables. There are a number of situations where it is not desirable for the table to impose a specific pre-determined motion. For example, where the structure is supported on soft soil, and the motion of the foundation depends on the dynamic response of the superstructure. In other cases, mid-level isolation systems are being used, were it may be possible to place the isolation system and the portion of the structure above the isolation plane on the table and to numerically model the portions of the building under the isolation plane. Lastly, it is possible to look at the response of structures with reactive mass dampers, where the mass is supported (on isolators, pendulum, etc.) on the shaking platform. The shaking table is modeled to mimic the response of the structure in which the damper is installed. Examples of these situations are presented, including cases were auxiliary actuators are used in conjunction with the hybrid table to simulate portions of the structure not physically included above the platform.

All of the examples presented are implemented using OpenFresco, the Open Source Framework for Experimental Setup and Control. All tests, and especially the hybrid tests are able to run in real time, and others are done rapidly depending on the limitations of the equipment involved, or the quality of the internet connections used. Opportunities for future research and collaboration on hybrid simulation and earthquake engineering are highlighted.