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(Hybrid Simulation to Assess Performance of Seismic Isolation in NPPs)

STATE-OF-THE-ART OF HYBRID SIMULATION TECHNIQUES

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ABSTRACT

The dynamic response of an isolated structure depends on the combined characteristics of the ground motion, bearings, and structure. To better understand this complex nonlinear interaction, and to validate and improve numerical models capable of quantifying the behavior of seismic isolators, and of the supported structures, systems and components, dynamic tests of isolated nuclear power plant models under realistic earthquake loading conditions are highly desirable. However, testing of large or full-scale models on nuclear facilities is costly and technically challenging using available earthquake shaking tables. In this paper, state-of-the-art hybrid dynamic simulation techniques were employed as the best available option to study the behavior of a representative nuclear power plant supported by full-scale seismic isolation bearings.

After reviewing the state-of-the-art in hybrid simulation, focusing on real-time and near real-time tests where portions of the structure are tested physically, and other portions are modelled computationally, efforts to upgrade an existing laboratory facility, previously used for dynamic testing of large seismic isolators, to be able to conduct hybrid simulations are discussed. This involved upgrading the control system to include a shared memory real-time network interface, and high speed computers for carrying out the numerical simulations and the computations used for controlling the motion of the electrohydraulic actuators that displaced the isolators in the test machine, as if it was installed under a nuclear power plant during an actual earthquake. Hybrid simulation was enabled through the use of OPEN Framework for Experimental Setup and COntrol (OpenFresco) in conjunction with the dynamic analysis platform OPEM System for Earthquake Engineering Simulation (OpenSees). Details of the hybrid control system, the test equipment, and of the numerical model of the IAEA/KEPCO Archetype Nuclear Test (ANT) power plant.

Three types of seismic isolation bearings were tested: a lead plug laminated rubber bearing, a flat sliding bearing with restoring force springs, and a triple pendulum friction isolator. The mechanical characteristics of these bearings were identified as part of the test program. Various earthquake motions were imposed to understand the behavior of the isolated plant under 1, 2 and 3 components of motion, imposed slowly and at or near real time. In this phase of the project, ground motions imposed were selected to represent design level shaking corresponding to standard NRC NREG 1.60 and EUR spectral shapes. In some tests, a single bearing was used to simulate the response of the isolated plant. In this case, no pitch, roll or yaw were permitted in the isolation plane. In other cases, the test bearing represented a group of bearings, and the other bearings supporting the ANT model were numerically simulated. These results identified some key characteristics of the seismic response of isolated nuclear power plants, including bearing responses, internal forces, and in-structure response spectra. In addition, important observations about the different types of bearings were made. The results of these tests have been used as the basis of the IAEA/KEPCO benchmark study of nuclear power facilities. A second phase of testing, considering beyond design basis earthquake motions, is under planning.