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FOREWORD

Special EESD issue on seismic protection techniques

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Seismic protection techniques are seismic design and construction strategies for mitigating the damaging effects of earthquakes on structures through the introduction of flexibility and/or energy-absorption capability within the structural system. These techniques involve the use of a special seismic protective system. The objective of adding the seismic protective system to new or the existing construction is to deflect earthquake-induced energy away from the structure and/or dissipate part of the earthquake-induced energy in elements not forming part of the gravity framing system. Key to this technique is limiting or eliminating inelastic action and damage to the gravity-load-resisting system, reduction of forces for the design of the foundation and, under certain conditions, reductions of accelerations and protection of non-structural systems. Seismic protective systems include seismic isolation, damping systems, adaptive systems, self-centering systems, active and semi-active systems and combinations of these, although so far only seismic isolation and damping systems have found widespread implementation and acceptance by the profession.

The origins of seismic protective systems may be traced to antiquity. The rocking columns of fourth century B.C. Greek temples and the sliding foundations of sixteenth century Islamic minarets in Asia are primitive but apparently effective seismic protective systems. The first documented example of a seismic protective system is the 1870 patent of Jules Touaillon of San Francisco for a strikingly modern seismic isolation system (the paper of Chang and Spencer in this issue utilizes this isolator in a modern active system). With a history of 140 years, some seismic protective systems have now reached the stage of widespread acceptance and implementation. Yet new systems are continuously proposed and studied, with a particular emphasis on active, semi-active and adaptive systems. In addition, studies concentrate on understanding the lifetime behavior and properties, in the advanced modeling of the mechanical behavior, in improving the reliability and in developing techniques for testing of seismic protective system hardware. The latter studies reflect the increasing number of implementation of these techniques in critical structures (e.g., hospitals and important bridges), in extreme multi-hazard environments (e.g., arctic conditions and offshore applications) and in extreme load and displacement demand applications (e.g., isolators of load-carrying capacity exceeding 150 MN and of displacement capacity exceeding 1 m have been implemented).

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This special issue of *Earthquake Engineering and Structural Dynamics* called for contributions on aspects of seismic protection techniques that (a) describe developments in seismic protective systems; (b) address issues of reliability and lifetime behavior of seismic protective system hardware; (c) describe the advanced modeling of behavior of this hardware; and (d) address issues of testing, scaling and similarity. Seven papers have been selected for this issue. These papers concentrate on the following topics (discussed in the order of appearance in the issue):

(a) *Assessment of performance of structures with seismic protective systems.* One paper by Huang, Whittaker and Luco presents a systematic methodology for assessing the seismic performance of seismically isolated nuclear power plant structures. The approach is applied to intensity-based, scenario-based and time-based assessment to evaluate probabilities of unacceptable performance. The approach is used to demonstrate the significant benefits offered by seismic isolation in reducing the probability of failure. The paper is of much contemporary value as new nuclear power reactors are seriously considered for construction in the United States and elsewhere. It is almost certain that such structures, when implemented in the United States, will make use of seismic protective systems.

(b) *Developments in seismic protective systems.* Three papers describe developments in adaptive and active seismic isolation systems. Morgan and Mahin describe developments in the design of triple friction pendulum seismic isolators to achieve functionality of the protected structure in occasional events and simultaneously achieve stable performance in very rare seismic events. This is achieved by designing the isolation system with adaptive properties so that stiffness and damping are dependent on the level of seismic hazard.

The paper by Tsai, Lin and Su describes the behavior of multiple friction pendulum isolators—an extension of the triple friction pendulum isolator that features an even more complex adaptive behavior. A novel mathematical formulation of behavior is presented and verified by comparison with the experimental results. The numerical simulations infer the advanced adaptive behavior offered by this isolator.

The paper by Chang and Spencer describes an active seismic isolation system and presents an experimental study that demonstrates the application and effectiveness of the system. Two features of this paper are worth mentioning. First, it systematically addresses the complex issue of active control with specially designed low-force actuators, advanced modeling of hardware and consideration of hardware limitations. Second, it utilizes a seismic isolator that was originally proposed in the 1870 patent of Jules Touaillon.

(c) *Modeling of behavior of seismic protective system hardware.* Two papers describe developments in modeling the behavior of seismic isolation hardware. The paper of Kikuchi, Nakamura and Aiken describes a phenomenological model of anisotropic behavior of square elastomeric bearings under ultimate load and deformation conditions. Importantly, the paper focus attention on the issue of dependency of behavior on the direction of loading, which so far has been ignored.

The paper by Kalpakidis, Constantinou and Whittaker addresses the modeling of the behavior of lead–rubber bearings that exhibit reduction of strength as a result of hysteretic heating in earthquake motion. A model based on first principles is presented and verified by comparison with the experimental results. Use of the model in analysis reduces the requirements for extensive isolator testing by comparison to the currently employed analysis approach that is based on multiple analyses with bounding property values. The model is utilized for the analysis of a sample isolated structure to demonstrate the significance of heating in the response prediction.

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(d) *Testing, scaling and similarity in seismic protective system hardware.* The paper of Kalpakidis and Constantinou address the topic of testing isolators in scale by concentrating on lead–rubber bearings. Based on a theory that predicts the effects of hysteretic heating on behavior, they proceed to determine how the bearing should be tested when full-size testing is not possible. It is demonstrated that when the bearing is reduced in size, the speed of the imposed motion should be increased by a factor equal to the length scale factor. This proves that the shake table testing of reduced scale specimens performed based on principles of dynamic similitude cannot capture the heating effects and direct extrapolation of results to the prototype scale is inappropriate.

As the guest editors of this special issue of EESD, we thank the Executive Editor, Anil K. Chopra, for his leadership of the journal and the focus on this topic, and the contributors and reviewers of the submitted papers, who made this issue possible.

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