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Optimal probabilistic design of seismic dampers for the protection of isolated bridges against near-fault seismic excitations

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ABSTRACT

A probabilistic, simulation-based framework is presented in this paper for risk assessment and optimal design of supplemental dampers for multi-span bridge systems supported on abutments and intermediate piers through isolation bearings. The adopted bridge model explicitly addresses nonlinear characteristics of the isolators and the dampers, the dynamic behavior of the abutments, and the effect of pounding between the neighboring spans against each other as well as against the abutments. Nonlinear dynamic analysis is used to evaluate the bridge performance, and a realistic stochastic ground motion model is presented for describing the time history of future near-fault ground motions and relating their characteristics to the seismic hazard for the structural site. A probabilistic foundation is used to address the various sources of structural and excitation uncertainties and ultimately characterize the seismic risk for the bridge. This risk is given by the expected value of the system response over the adopted probability models. Stochastic simulation is used for evaluating the multi-dimensional integral representing this expected value and for performing the associated optimization when searching for the most favorable damper characteristics. An efficient probabilistic sensitivity analysis is also established for identifying the importance of each of the uncertain model parameters in affecting the overall risk. An illustrative example is presented that considers the design of nonlinear viscous dampers for the protection of a two-span bridge.

1. Introduction

Applications of seismic isolation techniques to bridges (Fig. 1) have gained significant attention over recent years among researchers and practicing engineers [1–6]. Lead–rubber bearings or friction pendulum systems are typically selected for this purpose in order to isolate the bridge deck from its support, both at the abutments and potentially at the locations of intermediate piers. This configuration provides enhanced capabilities for energy dissipation during earthquake events while also accommodating thermal movements during the life cycle of operation of the bridge. It is associated though with large displacement for the bridge deck relative to its supports, especially under near-fault earthquake ground motions [7–9]. These motions frequently include a strong, longer-period component (pulse) that has important implications for flexible, isolated structures [10,11]. For base-isolated bridge systems, such large displacements under seismic excitations may lead (i) to large inelastic deformations and plastic hinging at the piers and abutments and (ii) to pounding of the deck between adjacent spans or against intermediate seismic stoppers or against the abutments supporting the ends of the bridge [8,12,13]. Such pounding will then lead to high impact stresses and increased shear forces for both the bridge deck and its supports (abutments and piers).

This overall behavior associated with excessive vibrations will ultimately lead to significant damage that affects not only the serviceability but also the structural integrity of the bridge system. For controlling such vibrations, application of seismic dampers has been proposed and applied to isolated bridges [2,13,14]. One of the main challenges in the design of such dampers has been the explicit consideration of the nonlinear behavior of the isolators and the dampers in the design process as well as proper modeling of the soil–structure interaction at the foundations of the bridge. Linearization techniques are frequently adopted for modeling the bridge system [14]; this simplifies the analysis, but there is great doubt if it can accurately predict the combined effect of the nonlinear viscous damping provided by the dampers along with the nonlinear hysteretic damping provided by the isolators, while appropriately addressing the soil–structure interaction characteristics and the nonlinearities introduced by pounding effects. Another challenge is the explicit consideration of the variability of future excitations and of the properties of the structural system, since a significant degree of sensitivity has been reported between these characteristics and the overall system performance [4,12].

This work introduces a simulation-based framework that addresses all aforementioned challenges for the design of supplemental dampers for seismically isolated bridges. A probabilistic foundation is used to address the various sources of uncertainty

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