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Seismic structural and non-structural performance evaluation of highly damped self-centering and conventional systems

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ABSTRACT

This paper evaluates the seismic structural and non-structural performance of self-centering and conventional structural systems combined with supplemental viscous dampers. For this purpose, a parametric study on the seismic response of highly damped single-degree-of-freedom systems with self-centering flag-shaped or bilinear elastoplastic hysteresis is conducted. Statistical response results are used to evaluate and quantify the effects of supplemental viscous damping, strength ratio and period of vibration on seismic peak displacements, residual displacements and peak total accelerations. Among other findings, it is shown that decreasing the strength of nonlinear systems effectively decreases total accelerations, while added damping increases total accelerations and generally decreases residual displacements. Interestingly, this work shows that in some instances added damping may result in increased residual displacements of bilinear elastoplastic systems. Simple design cases demonstrate how these findings can be considered when designing highly damped structures to reduce structural and non-structural damage.

1. Introduction

An important requirement of performance-based seismic design is the simultaneous control of structural and non-structural damage [1]. Structural damage measures are related to story drifts, residual drifts and inelastic deformations. Non-structural damage measures are related to story drifts, total floor accelerations and floor response spectra. Earthquake reconnaissance reports highlight that injuries, fatalities and economical losses related to failure of non-structural components far exceed those related to structural failures [2]. Explicit consideration of non-structural damage becomes vital in the design of critical facilities such as hospitals carrying acceleration-sensitive medical equipment which should remain functional in the aftermath of earthquakes [3].

Conventional seismic-resistant structural systems, such as steel moment resisting frames (MRFs) or concentrically braced frames (CBFs), are currently designed to experience significant inelastic deformations under the design seismic action [4]. Significant inelastic deformations result in damage and residual drifts, and hence, in economic losses such as repair costs, costly downtime during which the building is repaired and cannot be used or occupied, and, perhaps, building demolition due to the complications associated with straightening large residual drifts [5]. In addition, conventional seismic-resistant systems cannot provide harmonization of structural and non-structural damage since reduction of drifts or deformations and reduction of total floor accelerations are competing objectives, i.e., adding stiffness and strength to the structure decreases drifts and inelastic deformation demands but increases total accelerations [6].

Residual drift is an important index for deciding whether to repair a damaged structure versus to demolish it. McCormick et al. [7] reported that repairing damaged structures which had experienced residual story drifts greater than 0.5% after the Hyogoken-Nanbu earthquake was no financially viable. MacRae and Kawashima [8] studied residual displacements of inelastic single-degree-of-freedom (SDOF) systems and illustrated their significant dependence on the post-yield stiffness ratio. Christopoulos et al. [9] studied residual displacements of five SDOF systems using different hysteretic rules and showed that residual displacements decrease with an increasing post-yield stiffness ratio. An extensive study by Ruiz-Garcia and Miranda [10] showed that residual displacements are more sensitive to changes in local site conditions, earthquake magnitude, distance to the source range and hysteretic behavior than peak displacements. Pampanin et al. [11] studied the seismic response of multi-degree-of-freedom (MDOF) systems and highlighted a significant sensitivity of residual drifts to the hysteretic rule, post-yield

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