Dynamic Response of Steel Moment-Frame Structures with Hybrid Passive Control Systems

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The concept of the passive hybrid control system is studied through an analysis aimed at investigating the seismic response of steel moment-frame structures. Hybrid passive control systems consist of two different passive elements combined into a single device or system. Typically, a hybrid combination consists of a rate-dependent damping device paired with a rate-independent energy dissipation device. The benefit is the innovative configuration that exploits individual strengths and offsets weaknesses. One example is a high-damping rubber damper (HDRD) in series with a buckling-restrained brace (BRB). (See Figure 1) The HDRD dissipates energy under low level vibrations while the BRB provides only stiffness. For large deformations, the damper locks out and the BRB dissipates energy through yielding. The key to effective hybrid devices is allowing deformation to occur in the HDRD for minor earthquakes. The phased nature of the hybrid system makes it ideal for performance-based seismic design.

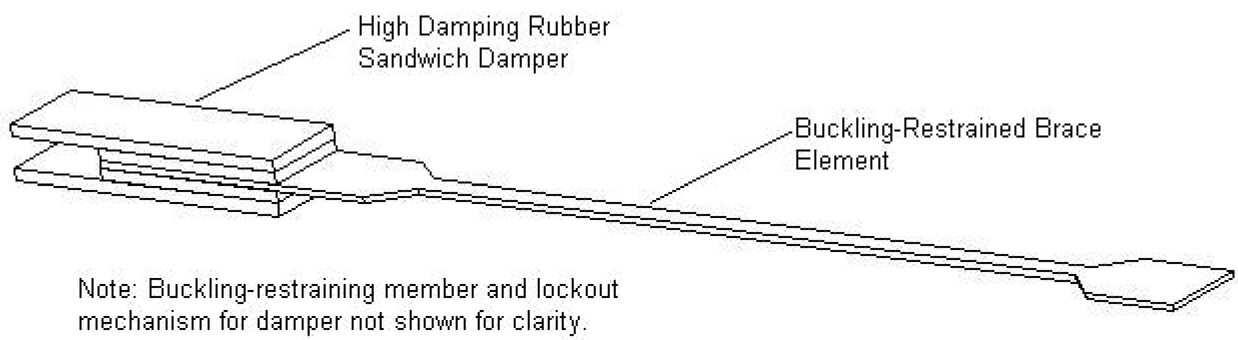

Figure 1 – Schematic Diagram of a Hybrid Passive Control Device

A 9-story, 5-bay special steel moment frame was used for the analysis. This moment-frame was then altered to create a reduced-strength frame. The reduced-strength structure was designed to demonstrate the performance of hybrid devices. Six configurations of seismic resisting systems were analyzed using the 9-story frame. The conventional systems included a plain SMRF and a reduced-strength SMRF-BRB dual system. The final four configurations are hybrid systems. The different hybrid configurations utilize a BRB and either an HDRD or a viscous fluid damper. For each of the hybrid systems, two gap sizes were used to investigate the effects. The analyses were run in the form of an incremental dynamic analysis (IDA). Several damage measures were calculated, including maximum roof drift, base shear and total roof acceleration. These results allowed for an overall performance analysis of the seismic response. Maximum story drifts and story residual displacements were also investigated. The two acceleration records were chosen to simulate different types of events. To investigate different seismic hazards, structures were designed for two locations.

The innovative concept of the hybrid passive control system has been analytically studied on a 9-story steel structure. The results demonstrate the capabilities of hybrid devices to improve seismic response. (See Figure 2) Each hybrid configuration improved some aspect of structural response with some providing benefits for all damage measures. The initial damping phase improved response for small events and in the latter part significant events. The large energy dissipation capacity of the BRB element reduced displacements for significant seismic events. The effect of the initial gap prior to engagement of the BRB was apparent in the results. The multi-phased performance of the hybrid device improves seismic response for all ranges of seismic events. The capability to essentially pre-program a structure to effectively respond to varying magnitude events meshes seamlessly into a performance-based framework and creates a safe and efficient structural system.

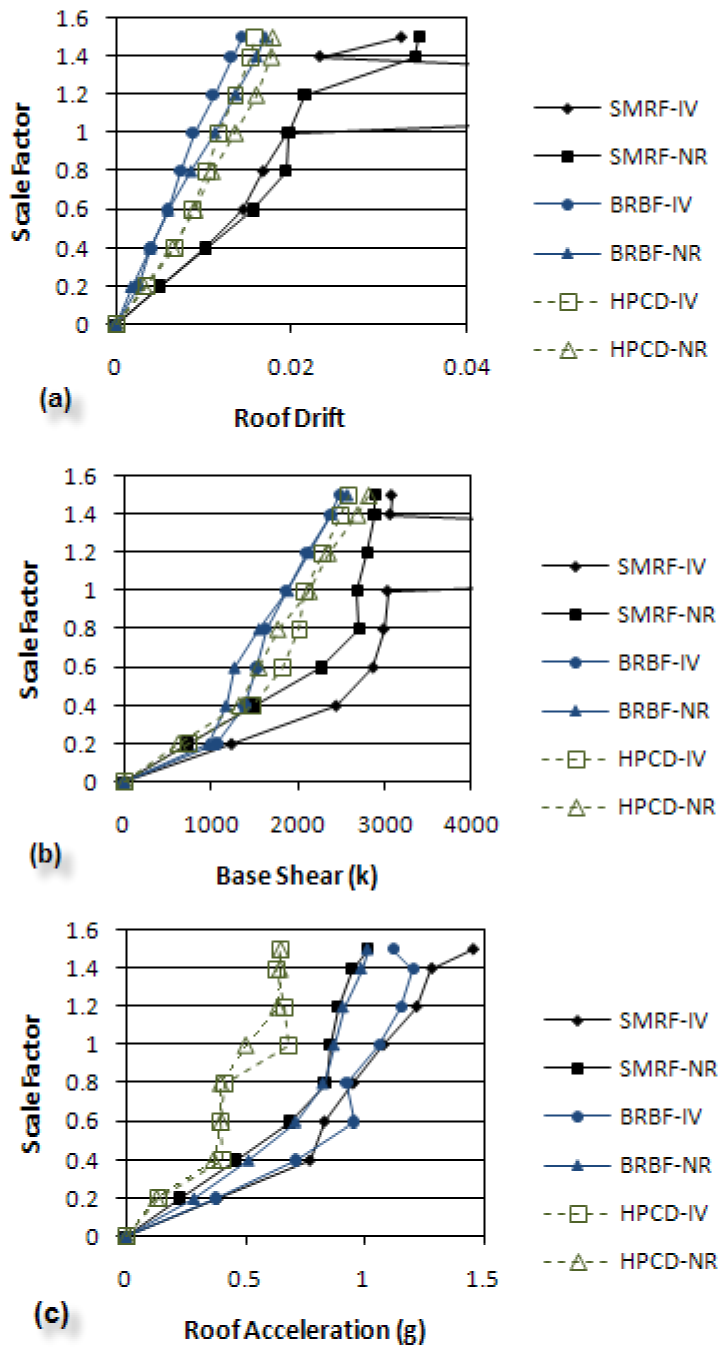

Figure 2 – IDA Analysis Results for a Hybrid Passive Control Device (HPCD) compared to a Special Moment-Frame (SMRF) and an SMRF-BRB Dual System (BRBF): (a) Roof Drift (b) Base Shear (c) Roof Acceleration