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Title: Moment Resisting Frames Coupled with Rocking Walls Subjected to Earthquakes

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Motivation

The high occupancy levels in urban multistory buildings, in association with current safety considerations inevitably leads to a reconsideration of performance objectives. In view of the appreciable seismic damage and several weak-story failures (some at mid-height) of multistory buildings that have been documented after major earthquakes, there has been a growing effort to develop an alternative hybrid structural system by coupling the response of moment resisting frames with rigid/stiff walls which are allowed to uplift and rock during ground shaking; therefore, enforcing a uniform drift distribution.

Figure 1. Left: A fourteen-story reinforced concrete apartment building in Anchorage, Alaska, was severely damaged during the 1964 Alaska earthquake. Right: Weak-story failure at the higher stories of the buildings after the 1995 Kobe, Japan Earthquake.

Objective

The main objective of this report is to understand the dynamics of the moment-resisting frames when they coupled with the rocking wall. In addition, the different configuration for the rocking wall, namely stepping rocking and pinned rocking wall is introduced and compared. The study also considers the effect of addition of restrainers and damping devices for the case of a stepping rocking wall.

Methodology

In this report first the full nonlinear equation of motion for the different configurations are derived and compared. Next, the dependability of single-degree-of-freedom model for the yielding spring coupled to rocking-wall is compared to a multi-frame yielding frame structure coupled to the rocking wall. Finally, given that the coupling of a moment-resisting building with a stiff rocking wall enforces a first-mode dominating response, our study proceeds by investigating the dynamic response of a yielding single-degree-of-freedom oscillator coupled to a stepping rocking wall in terms of inelastic spectra.

Conclusions

The report shows that a stepping wall suppresses peak and permanent displacements, with the heavier wall being most effective. In contrast, when the yielding oscillator is coupled with a pinned rocking wall, both peak and permanent displacements increase, with the heavier wall being most unfavorable. This unfavorable response is mainly because the moment from the weight of the pinned wall works against stability, and in most cases, it contributes to larger permanent displacements.

Subsequently, the report investigates the inelastic response of a yielding structure coupled with a vertically restrained rocking wall. The nonlinear equations of motion are extended for of a yielding oscillator coupled with a vertically restrained rocking wall, and the dependability of the one-degree of freedom idealization is validated against the nonlinear time-history response analysis the nine-story SAC steel frame that is coupled with a stepping vertically restrained rocking wall. The planar response analysis is conducted with the open-source software, OpenSees. While the coupling of weak building frames with rocking walls is an efficient strategy that controls inelastic deformations by enforcing a uniform inter-story-drift distribution, therefore, avoiding mid-story failures, our analysis shows that even for medium-rise buildings the effect of vertical tendons on the inelastic structural response is marginal, with the exception of increasing the vertical reactions at the pivoting points of the rocking wall. Accordingly, our planar response analysis concludes that for medium-rise to high-rise buildings, vertical tendons in rocking walls are not beneficial.

Given that the coupling of a moment-resisting building with a stiff rocking wall enforces a first-mode dominating response, our study proceeds by investigating the dynamic response of a yielding single-degree-of-freedom oscillator coupled to a stepping rocking wall with supplemental damping (either hysteretic or linear viscous) along its sides. The full nonlinear equations of motion are derived, and the study presents an earthquake response analysis in terms of inelastic spectra. The study shows that for structures with pre-yielding period $T1 < 1.0$ s, the effect of supplemental damping along the sides of the rocking wall is marginal even when large values of damping are used. The study uncovers that occasionally, the damped response matches or exceeds the undamped response; however, when this happens, the exceedance is marginal. The report concludes that for yielding structures with strength less than 10% of their weight, the use of supplemental damping along the sides of a rocking wall coupled to a yielding structure is not recommended. Our study concludes that supplemental damping along the sides of the rocking wall may have some limited beneficial effects for structures with longer pre-yielding periods (say $T1 > 1.0$ s). Nevertheless, no notable further response reduction is observed when larger values of hysteretic or viscous damping are used.

Keywords: seismic response modification, rocking wall, structural dynamics, earthquake engineering, seismic protection