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Investigating the Behavior of Self-Centering Base-Rocking and Double-Rocking Walls Subjected to Far-Field and Near-Field Earthquakes

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1. Introduction

There are two main mechanisms in self-centering systems: 1) restoring force mechanism, and 2) energy dissipation mechanism. These mechanisms provide flag-shaped force-displacement curves under cyclic lateral loads. The restoring force mechanism in rocking walls is produced by post-tensioned (PT) tendons, whereas the energy dissipation (ED) mechanism is produced by fuse elements. In mid and high-rise base-rocking walls, the higher mode effects result in increasing shear and moment at the core. By considering multiple rocking wall, the higher mode effects reduces. Using multiple rocking wall increases the inter-story drift and energy dissipation. Furthermore, residual displacement can be ignored in these systems.

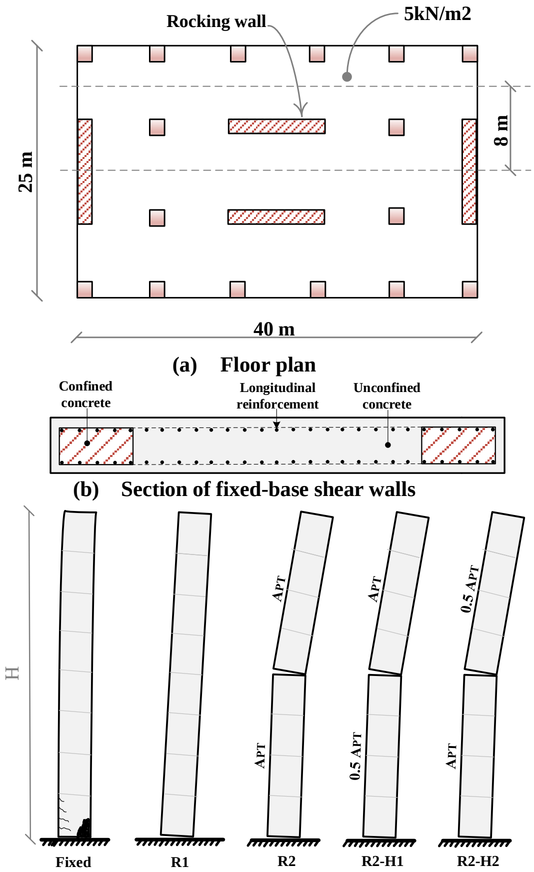
Higher mode effects in rocking wall design methods have been investigated. To consider higher mode effects, two design methods exist: 1) simplified modal superposition (SMS), and 2) modified modal superposition (MMS). Usually, the SMS method is more conservative than MMS method in estimating seismic demand.

It is shown that using dual-plastic hinge in base and middle heigth of fixed-base wall reduces higher mode effects. Therefore, dual-plastic hinge has sufficient efficiency for resistance against seismic loading.

In this research, the seismic behavior of self-centering rocking wall systems in both types of base-rocking and double-rocking was investigated. To conduct seismic analyses, three sets of seismic records were considered including 22 Far-Field (FF) ground motions and 28 Near-Field (NF) ground motions that half of which are Pulse-like (Pulse). These ground motions were used for nonlinear time-history analysis of structures with 8-, 12-, 16- and 20-floors. Based on the area of prestressing tendons, three types of double-rocking walls are considered and compared with the base-rocking and the fixed base walls. Numerical modelling was conducted via OpenSEES software in two-dimensional space. For validating, the available experimental data of base-rocking and fixed-base walls were used. To compare the seismic performance of the structures, some desirability coefficients were defined. These coefficients were based on the reduction of the higher mode effects and the reduction of the inter-story residual drifts. The results showed that generally, the double-rocking walls provide higher desirability coefficients than the other considered systems. Furthermore, the double-rocking walls by reducing the cable area in the bottom block (R2-H1) are more effective in reducing the effects of higher modes.

2. Prototype of Structures

Figure 1a shows the considered floor plan of research. The fixed base concrete wall was modeled by fiber section (Figure 1b). The design of structures were performed according to Pennucci et al. (2009) research. The considered structures have 8-, 12-, 16-, and 20 stories. The structures of fixed-base (Fixed), base-rocking (R1), and double-rocking were investigated (Figure 1c). According to Figure 1c, the double-rocking system has three types including: 1) without reducing the area of the PT tendons in height (R2), 2) with reducing the area of PT tendons in the bottom block (R2-H1), and 3) with reducing the area of PT tendons in the top block (R2-H2).



(a) Floor plan

(b) Section of fixed-base shear walls

(c) Examined of fixed-base and base-rocking wall

Figure 1. Properties of structures in the research

3. Verification of Numerical Modeling Process

To validate the numerical modeling process, the cyclic pushover results of OpenSEES model were compared to the experimental model. According to Figure 2, the fixed-base concrete shear wall and the base-rocking wall were verified via experimental researches of Orakcal and Wallace (2006), and Restrepo and Rahman (2005),

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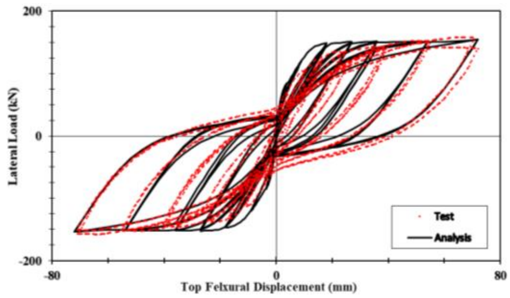
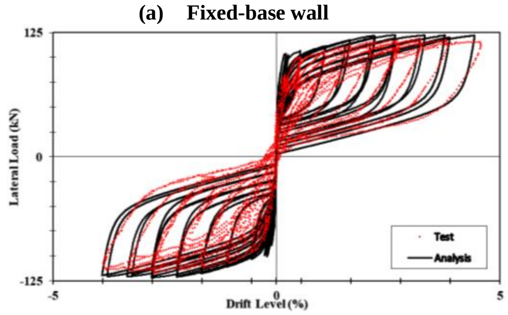
respectively. The results show good accuracy of numerical modeling.



(a) Fixed-base wall



(b) The base-rocking wall

Figure 2. Verification of numerical model via experimental model

4. Desirability Coefficients of Self-centering Rocking Walls

To examine the optimal case of structures three coefficients were defined. These coefficients include; 1) the index of reducing the moment of the double-rocking walls compared to the base-rocking walls, 2) the index of reducing the shear of the double-rocking walls compared to the base-rocking walls, and 3) the index of reducing residual drift compared to conventional shear walls. These desirability coefficients are defined as follows:

$$dc_1 = \text{Max}\left(\frac{\overline{\text{Max. Moment R1}_i} - \overline{\text{Max. Moment Rj}_i}}{\overline{\text{Max. Moment R1}_i}}\right)_{ns} \quad (1)$$

$$dc_2 = \text{Max}\left(\frac{\overline{\text{Max. Shear R1}_i} - \overline{\text{Max. Shear Rj}_i}}{\overline{\text{Max. Shear R1}_i}}\right)_{ns} \quad (2)$$

$$dc_3 = \text{Max}\left(\frac{\overline{\text{Max. Residual Drift of Fixed}_i} \text{-} \overline{\text{Max. Residual Drift Rj}_i}}{\overline{\text{Max. Residual Drift of Fixed}_i}}\right)_{ns} \quad (3)$$

5. Choosing Optimal Structures using Desirability Coefficients

With considering desirability coefficients, the optimal structures were selected (Table 1). According to this table, the R2-H1 wall is more efficient than other walls in reducing higher mode.

Table 1. Choosing optimal structures using desirability coefficients

Structure	FF	NF-No Pulse	NF-Pulse
08 Story	R2-H1	R2-H1	R2-H1
12 Story	R2-H1	R2-H1	R2-H1
16 Story	R2-H2	R2-H1	R2-H1
20 Story	R2-H1	R2-H1	R2-H1

6. Final Selection of Optimal Structures

To investigate final optimal structures, the selected wall in previous section must be checked by the requirements of design codes. In this research, the allowable drift and the stress ratio of tendons were considered as code requirements. After examining both checks, the walls of Table 2 are suggested for the considered structures subjected to different types of earthquake.

Table 2. Final selection of optimal structures

Structure	FF	NF-No Pulse	NF-Pulse
08 Story	R2-H1	R2-H1	R2
12 Story	R2-H1	R2-H1	R2
16 Story	R2-H1	R2-H1	R2
20 Story	R2	R2-H1	R2-H1

7. Conclusion

The most important results deduced from the time-history analyses of the numerical modellings are summarized as follow:

- In self-centering wall systems, residual displacements are negligible.
- The predominant mode of motion in self-centering base rocking walls (R1) under seismic loads are the first mode. As the height of the structure increases, the effects of higher modes increase. Furthermore, additional moment and shear demands are created in the rocking core.
- The double-rocking wall systems have been proposed to reduce the higher mode effects. The use of double-rocking wall with a ratio of areas less than the design values can have a great impact on reducing the demand for higher modes in the structure.
- To select the best seismic design, strength and stiffness controls were performed. For this purpose, the maximum inter-story drifts and the maximum stress ratio in the tendons were controlled.
- Since double-rocking wall under NF-Pulse records have large inter-story drifts, the double-rocking wall without reducing the tendon area (R2) was proposed for near-fault pulse like zone.
- In rocking wall under NF-No Pulse records, there is no problem of large inter-story drift or stress ratio of the tendons. Therefore, R2-H1 wall was proposed for near-fault without pulse like zone.

In rocking wall systems under FF records, R2-H1 wall was effective in 8, 12 and 16 story structures. In 20 story structures, due to the problem of large inter-story drift, R2 wall was proposed.