# SEISMIC STRENGTHENING OF FRAME BUILDINGS WITH WALLS ALLOWED TO UPLIFT ON THEIR FOUNDATION

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## 1. INTRODUCTION

The seismic performance of self-centering wall-frame structures subjected to near-fault ground motions contain larger velocity pulses is of increasing concern due to their destructive nature. These pulse-like motions may impose highly non uniform demands on the structure such that, under the maximum demand, the performance can exceed the level of code expectations for buildings design for different performance levels. In this study, the seismic performance of a four-story reinforced concrete (RC) frame building equipped with two rocking walls designed to confirm ACI 318 and ACI ITG-5.2 will be evaluated using three-dimensional finite element model. Two sets of ground motions containing 7 near-fault ground motions and 7 far-fault ground motions are used. The rocking wall system was designed as a retrofitting solution for existing RC frame structures, but equally suitable for use in new buildings. The results obtained under MCE-level ground motions are summarized in this paper.

## 2. BUILDING DESCRIPTION AND ROCKING WALL DESIGN

The details of prototype building are shown in Fig. 1. The design short period and 1.0 s spectral accelerations were $S_{MS} = 1.381g$ and $S_{M1} = 0.732g$, respectively. The design strength of the structural concrete was 28 N/mm$^2$. The floor live load and roof live load are 4.79 kN/m$^2$ and 0.96 kN/m$^2$ respectively. The typical column size is 400 mm x 400 mm. The typical floor beam size is 550 mm x 300 mm and roof beam size is 350 mm x 300 mm. The slab thickness is 200 mm.

The hybrid walls, investigated in this study use mild steel bars together with post tension tendons to resist lateral loads. The energy dissipation will be through yielding of mild steel bars. The wall height and length is 14.4 m and 5.0 m, respectively. The lateral loads on the hybrid walls were calculated using ASCE 7 (2010). When designing, the ACI ITG-5.2 (2009), specific guidelines for the design of special unbonded post-tensioned precast shear walls and ACI 318 (2011) were followed. The hybrid wall design was carried under two different drift limits: (i) Design drift limit according to ASCE 7 (2010) and (ii) Validation drift limit: according to ACI ITG-5.2 (2009).

## 3. MODELING AND ANALYSIS OF SELF-CENTERING WALL-FRAME BUILDING

Numerical analyses were carried out using OpenSees (2011). The gap opening behavior of the rocking wall was simulated by setting a zero tensile strength of wall concrete over a critical height ($H_{cr}$) of the wall. The $H_{cr}$ was taken as the confined concrete thickness of the wall. Confinement reinforcement details were not modeled along the region of $H_{cr}$. The unbonded mild steel bars were modeled using truss elements on the outside of the wall to have a uniform strain along the length of the element. The post-tensioned bars were modeled with co-rotational truss elements with initial strain material models. The overview of the finite element model for the wall is shown in Fig. 2. The Nonlinear Beam Column elements were used to model the beams and columns. The concrete and steel material models are chosen to be Concrete02 and Steel02, respectively. Response of the rocking wall-frame structure were evaluated under two sets of ground motions (7 per each) namely, near-field pulse-like and far-field (Fig. 3). It is important to highlight that the minimum damages to the wall was ensured during the design phase by providing spiral reinforcement at base of the wall. Therefore, the inter-story drifts (Fig. 4) indicate the degree of damage to the beams, columns and their connections only. Both near-fault and far-fault ground motions, resulted in a moderate damage to the structural building. Even though, the individual drift values are more than 1% under near-fault ground motions a negligible residual deformations were observed (Fig. 5). Hence, proves the superior performance of systems with self-centering walls.

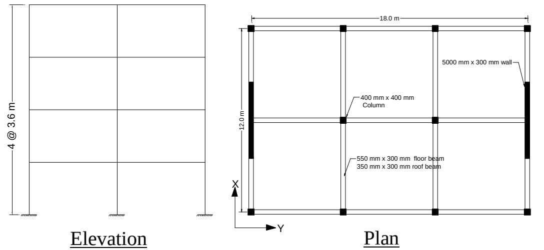


Fig. 1 Elevation and plan view of the prototype building

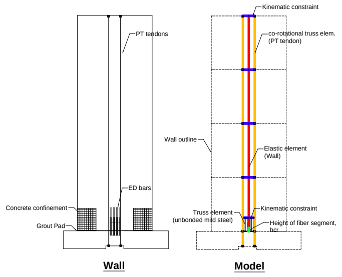


Fig. 2 Schematic of the wall and improved OpenSees model diagram of the wall

Keywords: self-centering wall-frame, near-fault, far-fault
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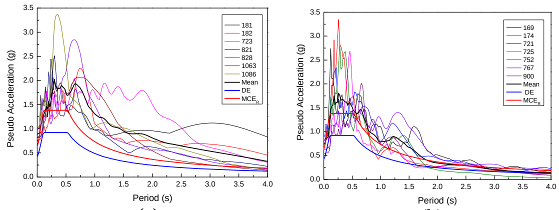
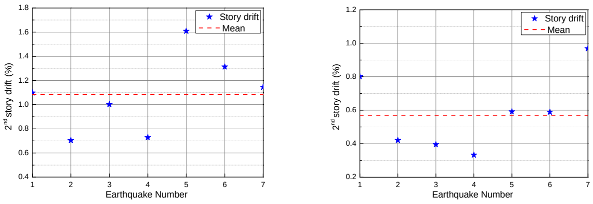



(a) (b)

Fig. 3 Comparison of 5%-damped response spectra of ground motions with the target spectra: (a) near-fault (b) far-fault




(a) (b)

Fig. 4 Story drift results: (a) near-fault ground motions; (b) far-fault ground motions

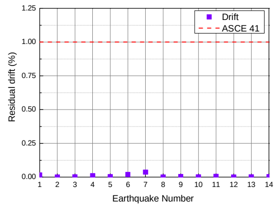



Fig. 5 Residual deformations under MCE-level ground motions

In order to illustrate the correlation among the maximum displacement demand and the velocity pulses of near-fault ground motions, a Fig. 6 is plotted. An equivalent pulse of ground motion, which is defined by two parameters namely, pulse period ($T_p$) and pulse amplitude ($A_p$), is used to represent the near-fault ground motions. The ground motion records selected used in this study is found to have a longer pulse period compared with the first mode fundamental period ($T_1$) of the building ($T_1 < T_p$). The maximum displacement demand is observed to be decrease when $T_p/ T_1$ ratio increases, and increases with the $A_p$ of ground motions. Thus, it can be concluded that behavior of structures could be primarily influenced by the velocity pulses in the ground motions. In addition to that, the presence of lateral load bearing walls in the structure will increase the shear demand on buildings. The base shear on the building under near-fault ground motions were found to be under go sudden changes, with compared to far-fault ground motions (Fig. 7). Hence, strengthening of wall foundations are required to accommodate the increase shear demand in walls.

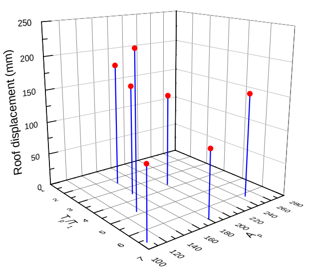
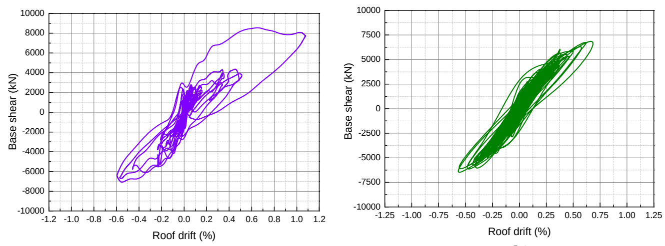



Fig. 6 Correlation of the peak story displacement demand with the pulse characteristics of near-fault ground motions.




(a) (b)

Fig. 7 Typical base shear vs. drift demand for MCE-level ground motions: (a) EQ. 181; (b) EQ. 169

## 4. DISCUSSION AND CONCLUSIONS

Under MCE-level, moderate type of damage to the building is expected for both near-fault and far-fault ground motions. Mean story-drift ratios under near-fault ground motions were estimated to be 35% and 59% larger than those for far-fault ground motions under DE and MCE-levels, respectively. Moreover, the seismic demands under near-fault ground motions were found to be closely correlated with the equivalent pulses of the ground motions. More interestingly, a negligible residual deformation of the building was observed after following a sever ground motions. However, consideration should be given during the evaluation of base shear demand under near-fault ground motions.

## REFERENCES.

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