Performance Evaluation of Post-tensioned Hybrid Precast Wall Buildings under Short and Long Duration Ground Motions

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Abstract— **Seismic performance of post-tensioned hybrid precast wall (PHW) systems has been mainly studied in the past employing short duration ground motion records. The present study compares the multilevel seismic response of PHW buildings under long and short duration ground motions records. Results obtained from nonlinear dynamic analysis of 4-, 6-, and 8-story PHW show reduction in collapse capacity under long duration earthquakes.**

I. Introduction

Post-tensioned hybrid precast concrete wall (PHW) is a type of rocking wall that utilizes energy dissipating (ED) steel bars at the base joint and unbonded post-tensioning (PT) extending from the foundation to the roof (Fig. 1)[1]. The ED bars dissipate input seismic energy, thus limiting damage to the structural components and PT tendons provide self-centering capacity, thus limiting residual deformations.

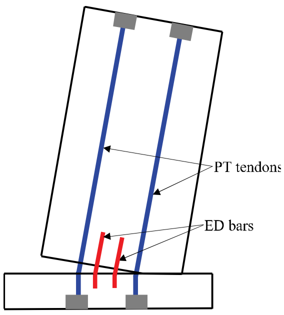

Fig. 1. Schematic of a post-tensioned hybrid precast wall[2].

Regions near active subduction zones are susceptible to large magnitude earthquakes and consequent long duration shaking. Although current seismic design codes and standards do not explicitly account for the duration of ground motion, recent studies[3],[4] have highlighted that long duration earthquakes could significantly increase the probability of collapse for different structural systems. However, no such study has been carried out for PHW system. More importantly, comparison of the collapse risk of PHW buildings under long and short duration ground motions can provide implications for the design of PHW.

II. Building Description and Design

Three archetype buildings: 4-, 6-, and 8-story are considered for this study. Two PHWs are placed on the outer frames along the transverse (N-S) direction to resist all the seismic action in this direction (Fig. 2). All three archetypes are designed for an arbitrary location with risk-targeted maximum considered earthquake (MCE_R) spectral acceleration ordinates $S_s = 1.642g$ and $S_1 = 0.586g$ (where g is acceleration due to gravity).

One of the two PHWs is considered for the subsequent design and analyses. This wall is designed as special reinforced concrete shear wall with response modification coefficient, $R = 6$. To facilitate enough energy dissipation as well as self-centering behavior, all PHWs are designed for ED moment ratio, $\kappa = 0.50$[5]. The base joint of PHW and wall reinforcements are designed to satisfy the ACI ITG-5.2[6] requirements. Both design earthquake and MCE_R level demands are considered for the design of PT tendons and ED bars.

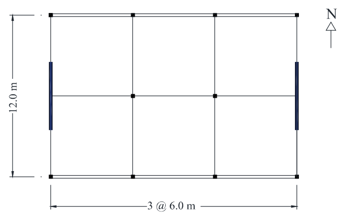

Fig. 2. Plan view of the archetype PHW buildings.

III. Numerical Modeling

Two-dimensional models of the buildings are developed in OpenSees[7] considering both material and geometric nonlinearities. The fiber-based modeling approach[5] utilizing combination of beam-column elements for wall panels, corotational truss elements for the PT tendons, and truss elements for the ED bars, is used in this study. Gap opening at the wall base is simulated using a displacement-based beam-column element with compression-only concrete fibers over a critical height H_{cr} from the base. Fracture of the PT tendons and ED bars is simulated by assigning strain limits to the respective materials. A leaning column is used to account for the destabilizing $P-\Delta$ effects from loads on the gravity system.

IV. GROUND MOTION RECORDS

To isolate the effect of ground motion duration from the influence of amplitude and spectral shape, sets of spectrally equivalent (records having similar response spectra but different duration, Fig. 3) long and short duration records are employed to conduct the nonlinear response history analysis (NLRHA). The $5-75\%$ significant duration (Ds_{5-75}) is taken as the ground motion duration metric, based on the findings of Chandramohan et al.[3] . Records with Ds_{5-75} greater than $25\,\text{sec}$ are categorized as long duration records. This study utilizes 77 pairs of spectrally equivalent records from Bravo-Haro and Elghazouli[8].

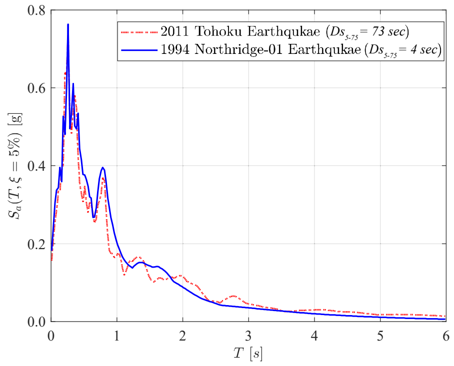

Fig. 3. Response spectra of a spectrally equivalent long and short duration ground motion record pair.

V. ANALYSIS RESULTS

To obtain the collapse fragility curves, incremental dynamic analysis (IDA) is conducted until collapse under the two record sets. A direct comparison of geometric mean IDA curves for the long and short duration sets is presented in Fig. 4(a) for 4-story PWF building. These curves diverge at higher ground motion intensities with long duration records consistently predicting lower collapse capacities. The median collapse capacity ($\hat{S}_{CT}$) for the 4-PHW estimated using short and long duration sets are $3.47g$ and $3.24g$, respectively. As the ground motion sets are spectrally equivalent, this reduction in collapse capacity is attributed to the difference in significant duration of the two records sets.

Results from IDA are used to obtain the parameters of fragility curve. Shown in Fig. 4(b) are the collapse fragility curves for the 4-story PHW building estimated using short and long duration record sets. The probability of collapse at MCE_R (100% scaling level) increases from 10% for the short duration set to 16% for the long duration set. Results from other buildings also lead to similar conclusions.

VI. CONCLUSIONS

Based on the numerical results of the buildings considered, the following conclusions are drawn:

1. The effects of ground motion duration are seen at ground motion intensities large enough to cause significant damage to the wall concrete and dynamic instability.
2. Long duration records can significantly reduce the collapse capacity and increase the probability of collapse at MCE_R level shaking for the PHW buildings.

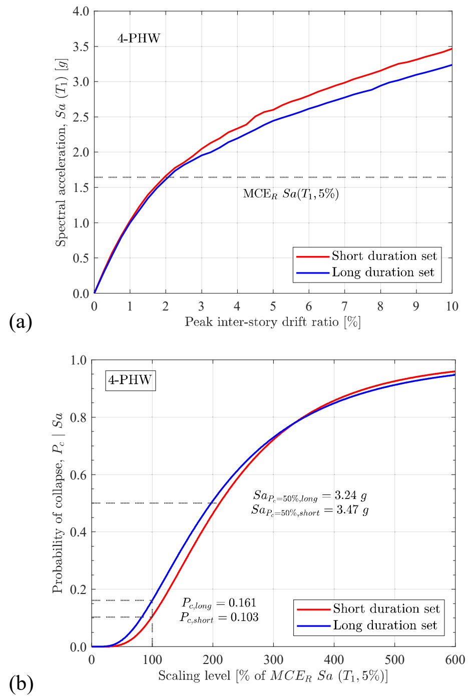

Fig. 4. Comparison of: (a) geometric mean IDA curves; and (b) collapse fragility curves; for 4-PHW estimated using spectrally equivalent long and short duration record sets.

These findings highlight the need to explicitly consider expected shaking duration in the seismic design and assessment of PHW buildings.

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