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SEISMIC RESPONSE OF A FLAG-SHAPED HYSTERETIC BEHAVIOR UNDER GROUND MOTIONS

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Self-centering systems have attracted significant interest in earthquake-engineering research, due to their excellent performance under simulated seismic loading through their self-centering capabilities. A comprehensive parametric study is presented to compare the ductility demands on single-degree-of-freedom (SDOF) systems, when subjected to ground motions with a probability of exceedance of 10% in 50 years in California. The influences of different parameters were analyzed under SDOF structural responses in terms of displacement ductility and absolute acceleration. The responses of the flag-shaped hysteretic SDOF systems were also compared against the responses of similar bilinear elasto-plastic hysteretic SDOF systems. Two ensembles of far-field and near-fault historical earthquake records, corresponding to ordinary earthquakes, were used for the parametric study to compare the ductility demands. Although a flag-shaped hysteretic SDOF system of equal or lesser strength can often match or better the response of an elasto-plastic hysteretic SDOF system with almost no residual drift, the analysis shows that seismic design of self-centering systems should account for the difference between far-field and near-fault ground motion.

Keywords: Self-centering systems, Hysteretic behavior, Mean displacement ductility, Far field, Near fault.

1 INTRODUCTION

Currently, structures are often designed according to seismic codes for the Life Safety Performance, as defined by the Federal Emergency Management Agency's FEMA 356 (2000). This allows for the possible repair of the lateral-force resisting system (LFRS) under moderate to strong earthquakes, and possible damage beyond repair with large deformations from strong earthquakes. However, the cost to restore the operation of the building can be significant, if not prohibitive, when compared with the cost of the structure itself. One way of counteracting the residual deformations is to create structure systems that can return to their original positions, such as a self-centering system with a flag-shape hysteresis behavior (FSHB) (Priestley 1991, Christopoulos et al. 2001, Ricles et al. 2001, Christopoulos et al. 2002, Chou et al. 2006, Morgen and Kurama 2008, Tremblay et al. 2008, Guo et al. 2013, Song et al. 2013). A FSHB system as shown in Figure 1 is appealing, due to a combination of a linear-elastic hysteresis represented by a post-tension element, and an elastic-plastic hysteresis represented by any energy dissipation device. This study presents a parametric study to compare the ductility demands of a single-degree-of-freedom (SDOF) structure with FSHB.

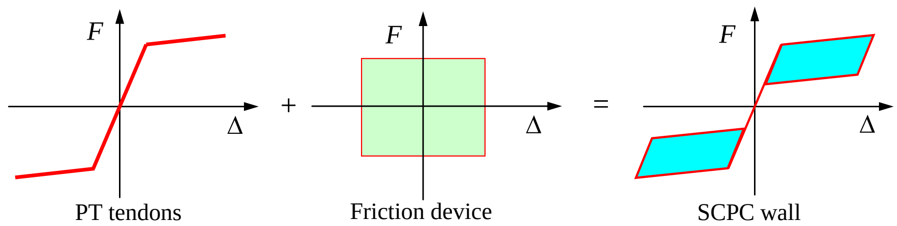

Figure 1. Conceptual flag shape hysteretic behavior (Guo et al. 2013).

2 NORMALIZED SDOF EQUATION OF MOTION

The equation of motion for a SDOF system subjected to external excitation force can be expressed as

$$m\cdot \ddot{x} + c\cdot \dot{x} + F(x, t) = -m\cdot \ddot{x}_g \quad (1)$$

where *m* is the structural mass; *c* is the viscous damping coefficient; F(x) is the non-linear restoring force of the FSHB system; $\ddot{x}$, $\dot{x}$ and x are the acceleration, velocity and displacement responses of the SDOF structure; and $\ddot{x}_g$ is the selected ground acceleration. The linear-elastic natural period $T0 = 2\cdot\pi\cdot (m/k_0)^{1/2}$ and the strength ratio $\eta = F_y/(m\cdot g)$ can be used as key parameters to define the dynamic response of a non-linear SDOF system, where k_0 is the initial linear elastic stiffness of the system; Fy is the yield fore; and g is the gravity acceleration. For the bilinear elastic-plastic behavior shown in Figure 1(a), a SDOF can be completely defined by specifying a level of critical damping, an initial period T_0, and a strength level η. For the flag shape hysteresis in Figure 1(b), parameters α and β are necessary to define the restoring force-displacement relationship.

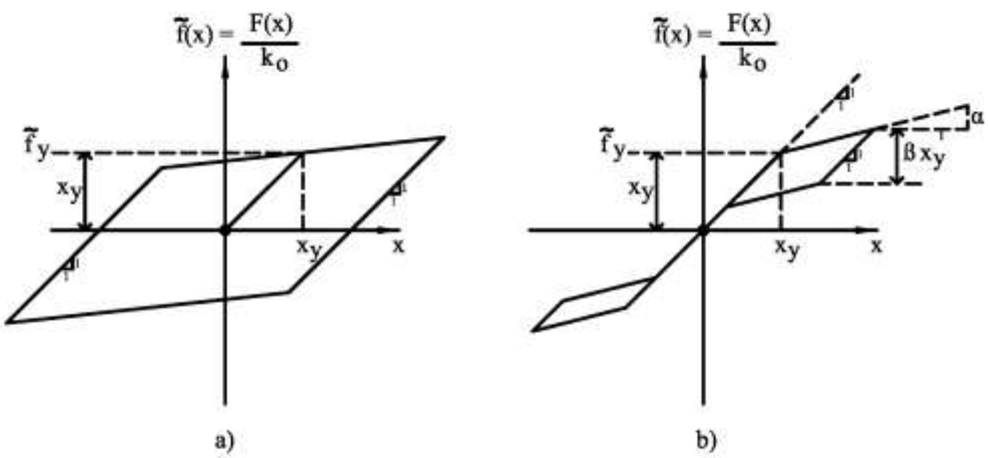

Figure 2. Idealized force-displacement relationship: a) typical elastic-plastic connection, and b) post-tensioned connections with energy dissipation.

3 GROUND MOTIONS FOR PARAMETRIC STUDY

Two sets of records were used in this study, representing twenty far-field and near-fault events, respectively. The 20 scaled far-field ground motions represent Californian earthquakes with a probability of exceedance of 10% in 50 years, and were recorded on soil types C or D with magnitude ranging from 6.7 to 7.3. The second set of 20 near fault earthquake records has the distance from fault less than 10 km. Figures 3 and 4 present the response spectra for both sets of records.

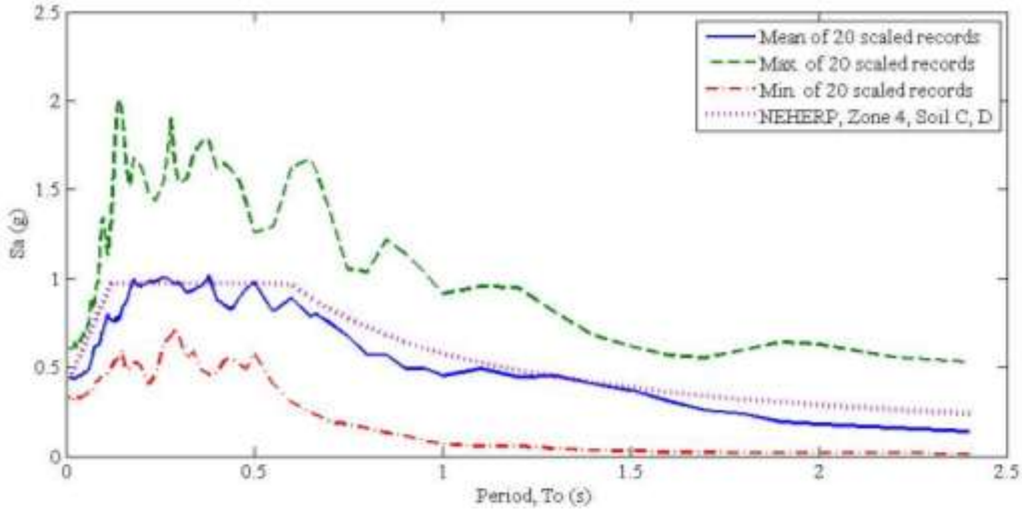

Figure 3. Response spectra of scaled far field ground motions.

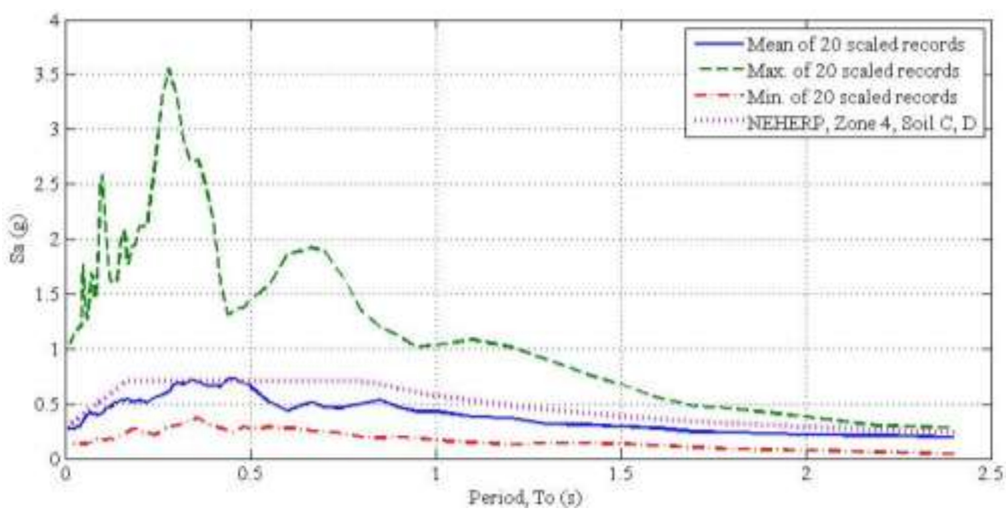

Figure 4. Acceleration response spectra 20 scaled near fault ground motions.

The mean displacement ductility is a normalized non-dimensional index that can be utilized to characterize the inelastic response of SDOF. It can be used to determine both the structural and non-structural damages to buildings under seismic loading. A higher-mean displacement ductility will represent a higher risk of failure on the structure. The mean displacement ductility is defined as:

$$\bar{\mu}_{\Delta} = \frac{Average\left[max_{0 \le t \le td}\left|x(t)\right|\right]}{x_y} \tag{2}$$

where t_d is the duration of ground motion. The results of the mean displacement ductility over the ensemble of earthquakes are shown in Figure 5 for far-fault ground motions and in Figure 6 for near-fault ground motions. It can be observed that the increments of α and β decrease the mean displacement ductility for all cases. Increasing α and β will make the system stiffer. As a result the maximum displacement of the system will decrease.

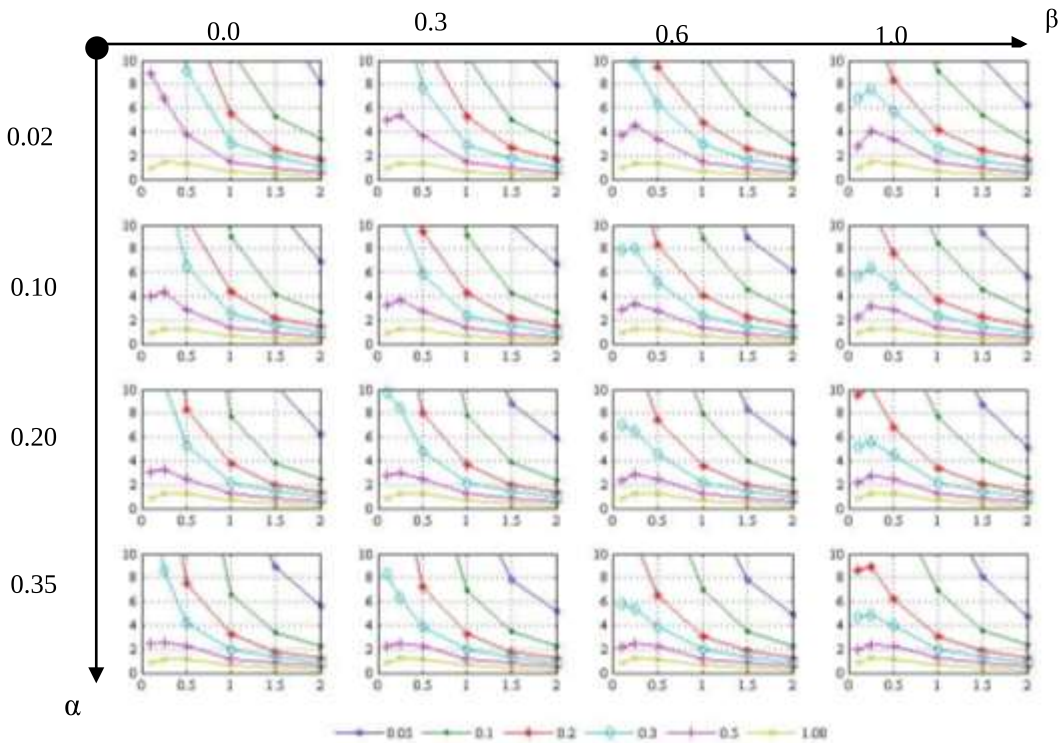

Figure 5. Mean displacement ductility for far-field fault ground motions.

The increment of α creates a major impact on the reduction of $\bar{\mu}_{\Delta}$. This can be observed by taking the difference between values with the same β and various α. Note that the impact gets reduced once the strength ratio and period increase. Increasing values of the period T will decrease values of $\bar{\mu}_{\Delta}$. The reduction is more notorious for values of T < 1s. Decreasing the strength factor η is observed to increase the mean displacement ductility. This increment is more extreme when η ≤ 0.3. The reduction on the strength factor η will represent a reduction on the yielding limit Fy. This means that the system will be more prone to deformation, increasing the displacement on the system.

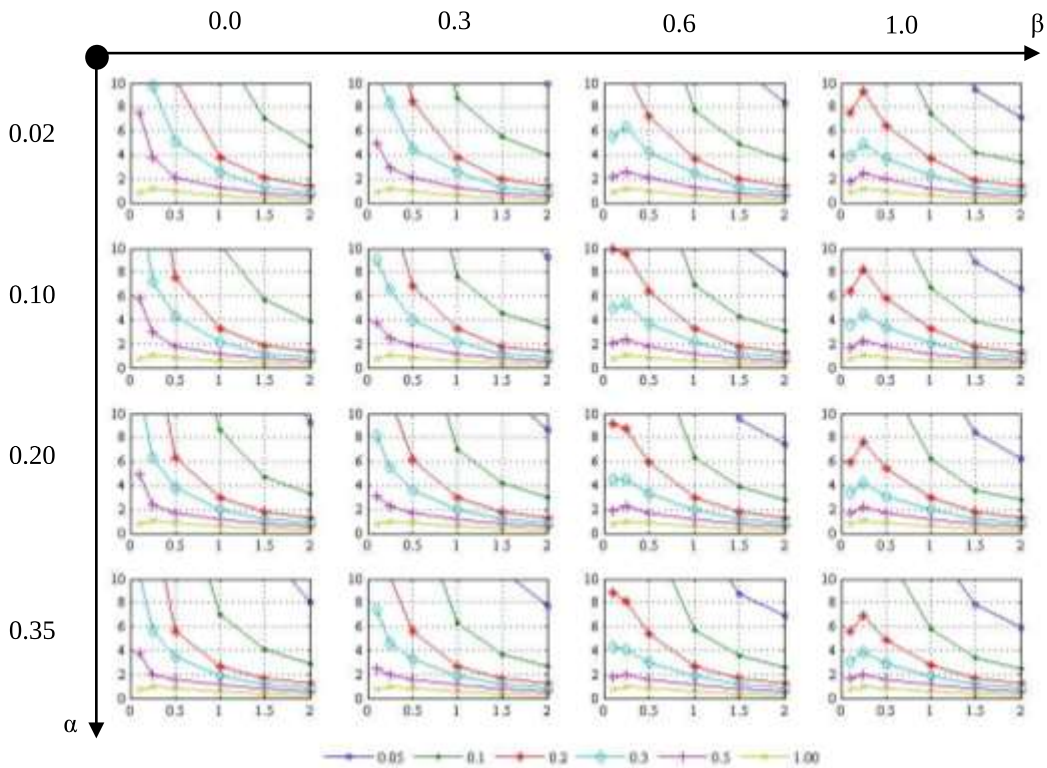

Figure 6. Mean displacement ductility for near field fault ground motions.

4 SUMMARY AND CONCLUSION

The seismic response of a SDOF system with a flag-shaped hysteretic model was investigated when subjected both far-field and near-fault ground motions. The flag-shaped hysteretic behavior is defined by a post-yielding parameter α and energy dissipation parameter β. The influences of α and β were captured by analyzing the changes on the mean displacement ductility $\overline{\mu}_{\Delta}$. The results indicated that for short initial periods and for low strength levels, the mean displacement was more likely to decrease by increasing the values of α as opposed to increasing the values of β. This behavior was reversed for long-period models with high-strength levels.

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