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NUMERICAL EVALUATION OF BASE-ISOLATED STRUCTURES WITH OPTIMIZED DISTRIBUTION OF LRB AND FPS ISOLATORS

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ABSTRACT

Seismic base isolation is an earthquake resistant design method that is based on decreasing the seismic demand instead of increasing the seismic capacity. In this paper, the seismic response of base-isolated structures is numerically investigated. The effectiveness of an isolation system depends upon the dynamic characteristics of earthquake ground motion and the building superstructure. In order to evaluate the dynamic response of nonlinear base-isolated structures, different detailed 3D nonlinear analytical models with different characteristics are developed and analyzed under significant and strong motion earthquakes. Also in order to have the optimized behavior of system, different types of isolators including Lead-Rubber Bearing (LRB) and Friction-Pendulum (FPS) isolators were simulated between the superstructure and the foundation so as to provide lateral flexibility and energy dissipation capacity. Providing an optimized arrangement of different types of isolators in the structure is important since it affects the structural responses to earthquakes. The parametric study is concentrated on base shear, accelerations and displacements of isolated models. Also the comparison between hysteretic responses of models as a main criterion for energy dissipation of system has been investigated and evaluated. Results show that the model with FPS ratio of 25% has the best structural response against seismic loads.

Introduction

In order to minimize inter-story drifts, in addition to reducing floor accelerations, the concept of base isolation is increasingly being adopted. Base isolation has also been referred to as passive control, as the control of structural motions is not exercised through a logically driven external agency, but rather through a specially designed interface at the structural base or within the structure, which can reduce or filter out the forces transmitted from the ground (Pradeep Kumar & Paul 2007).

Isolators can be classified as sliding and elastomeric (Taylor, et. al. 2004; AASHTO 1999). Previous research on building response as a function of isolator type revealed that

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elastomeric isolators acquire larger base displacements but transmit lower accelerations to the superstructure compared to sliding isolators (Matsagar and Jangid 2004; Ordonez et. al. 2003; Jangid and Kelly 2001). Smaller seismic isolation displacements indicate lower cost in isolators, lower cost in installation and lower structural cost for providing required gaps (Skinner et. al. 1993). Similar comparative studies for structures are limited (Dicleli and Buddaram 2006).

Among others, two isolator types that are representative of sliding and elastomeric systems are the Friction Pendulum System (FPS) and the Lead-Rubber Bearings (LRB) respectively. There are unique differences in the vertical response characteristics of elastomeric and sliding isolators. The conventional FPS is essentially rigid under compression and has no tensile load capacity while the LRB has relatively less compression stiffness and able to resist a limited amount of tensile loading (Naeim and Kelly 1996). Previous researches have been generally concentrated on investigation of base isolation systems with a unique type of isolators (for instance, LRB or FPS isolators) (Almazan 1998 and Kelly 2003). In this paper a combination system consist of both LRB and FPS isolators has been investigated and the optimized system has been evaluated under two major earthquakes of Elcentro and Manjil.

Structural Models

Since the main purpose of the present study is to achieve a proper model with optimized distribution of LRB and FPS isolators, five different structural models with different ratios of isolators were constructed. The first model consists of only FPS isolators (Ratio of FPS= 100%). In the second model, the ratio of FPS isolators was decreased to 75% and the remaining 25% was substituted by LRB isolators. This pattern was repeated to other models by changing the ratios of FPS and LRB isolators to construct other three structural models. A typical plan was selected for the analyzing the structural models and is shown in Figure 1.

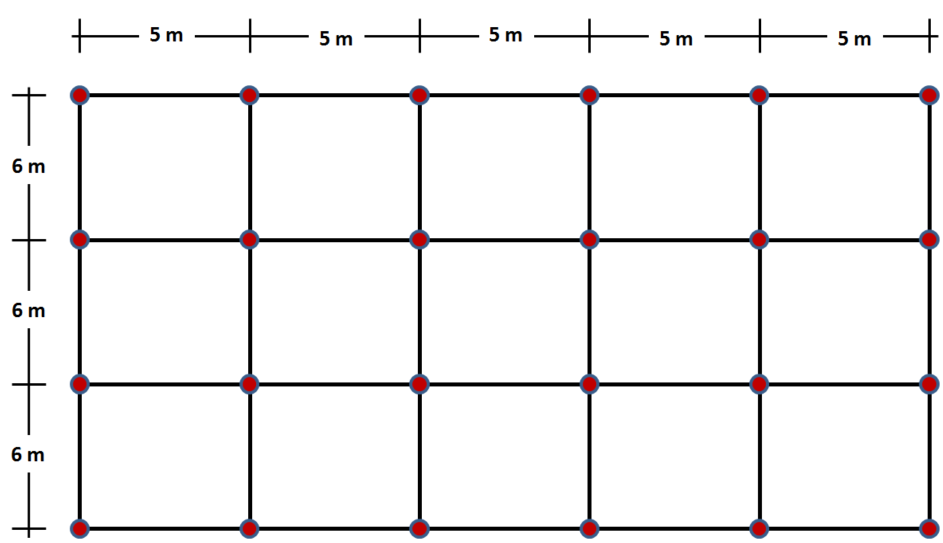

Figure 1. Typical plan selected for structural analyses.

Analytical Modeling

In order to analyze the structural models, 3D-BASIS-ME-MB that is a computer program for nonlinear dynamic analysis of seismically isolated structures, was used (Tsopelas et al. 2005). The structural models were analyzed under 2 dominant earthquake time-histories of Elcentro and Manjil which are normalized. The characteristics of both earthquakes and the convergence procedures of modal parameters are presented in Table 1 and 2 respectively.

Table 1. Characteristics of earthquakes used for analysis.

Earthquake	Year of Occurrence	Peak Acceleration	Duration Time
Elcentro	1940	0.348g	53.74 sec
Manjil	1990	0.514g	53.5 sec

Table 2. Convergence Procedures of Modal Parameters.

T_D (Sec)	D (m)	K_{eff} (ton/m)	W (ton)	Q (ton)	K_2 (ton/m)	K_1 (ton/m)	D_y (m)	Q (ton)
2	0.24874	2613.15	101.537	102.05	2202.88	22028.8	0.00463	103.987
2	0.24874	2613.15	101.537	103.987	2195.1	21951	0.00474	104.031
2	0.24874	2613.15	101.537	104.031	2194.92	21949.2	0.00474	104.032
2	0.24874	2613.15	101.537	104.032	2194.91	21949.1	0.00474	104.032
2	0.24874	2613.15	101.537	104.032	2194.91	21949.1	0.00474	104.032

Numerical Results

In this section the analytical results are presented and evaluated for each type of distribution of isolators. The first model includes 4-story building with only FPS isolators and is considered as control model to compare with the other four models. The analytical results are presented and evaluated for isolators design period of 2 seconds.

Comparison of Seismic Responses of Different Models under Manjil Earthquake

The hysteretic responses of all five models are shown in Figures 2 to 6. By considering the hysteresis loops of all models, it can be concluded that the energy dissipation of models with FPS ratio equal to 0 and 25% are the best among all models. Maximum amounts of response for different models under Manjil earthquake is summarized in Table 3; these responses include maximum base shear to weight of superstructure, maximum base displacement at center of mass and maximum acceleration. A comparison of amounts of Table 3 is presented as a bar chart shown in Figure 7. By examination of the bar chart, it is obvious that the least acceleration of superstructure is occurred in model with FPS ratio equal to 25%. By assuming the responses of control model (model with only FPS isolators) as the base values, the decrease and increase of other models responses are calculated and summarized in Table 4 and Figure 8. The negative values in Table 4 refer to increase in response relative to control model. The maximum decrease in acceleration has been occurred in model with FPS ratio of 25% by about 6 percent while its decrease in base displacement is about 1 percent which is the least amount among all models.

Since reduction of acceleration in superstructure and energy dissipation capability of system are two principle and substantial parameters in selection of isolation systems, by considering the hysteresis loops and the bar charts it can be concluded that the model with FPS ratio of 25% shows the best structural behavior against earthquake event of Manjil.

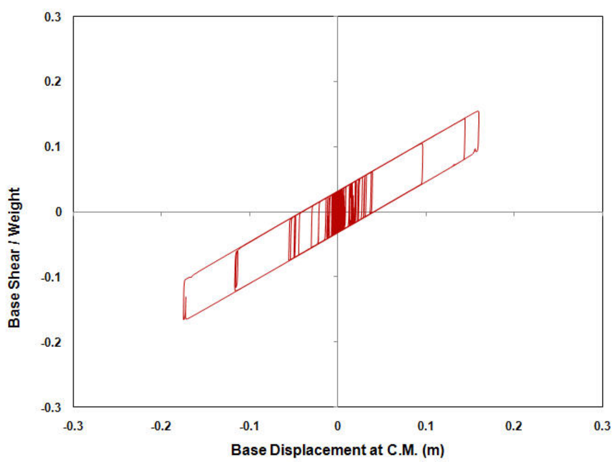

Figure 2. Hysteretic response of model FPS ratio of 100%.

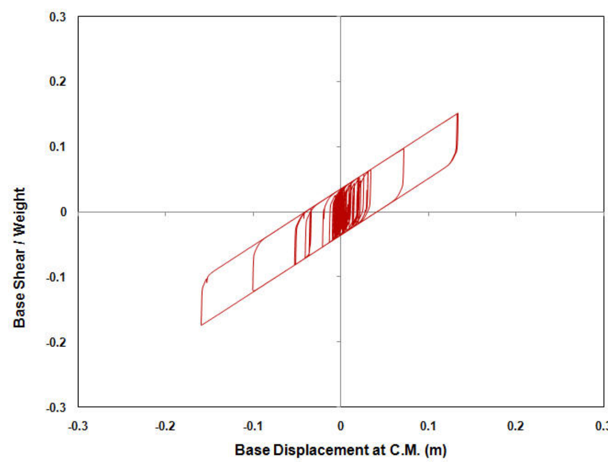

Figure 3. Hysteretic response of model FPS ratio of 75%.

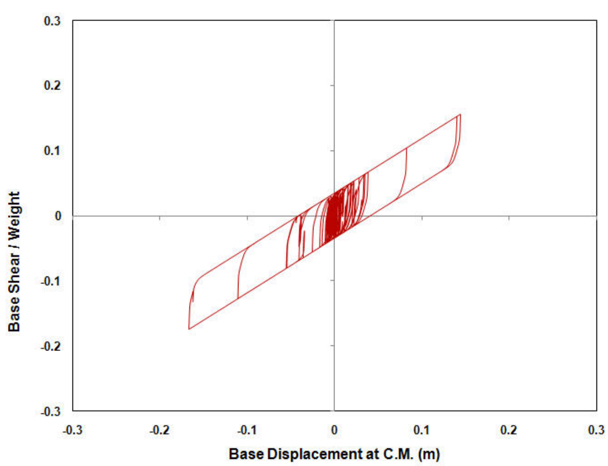

Figure 4. Hysteretic response of model FPS ratio of 50%.

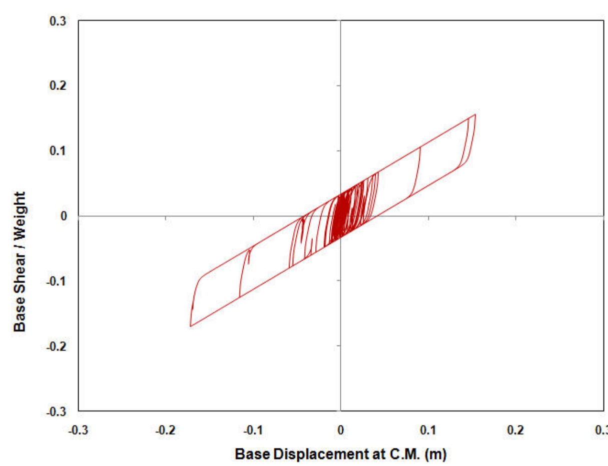

Figure 5. Hysteretic response of model FPS ratio of 25%.

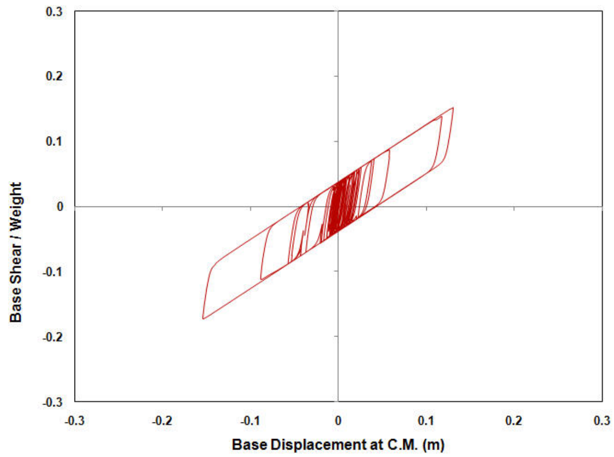

Figure 6. Hysteretic response of model LRB ratio of 100%.

Table 3. Maximum responses of different structural models under Manjil earthquake.

TYPE	Base Shear/Weight (max)	Base Disp. at C.M. (max) (m)	Acceleration (max) (g)
FPS	0.1653	0.1745	0.1983
75% FPS- 25%LRB	0.1740	0.1591	0.2139
50% FPS- 50%LRB	0.1737	0.1668	0.1947
25% FPS- 75%LRB	0.1704	0.1723	0.1862
LRB	0.1721	0.1538	0.2209

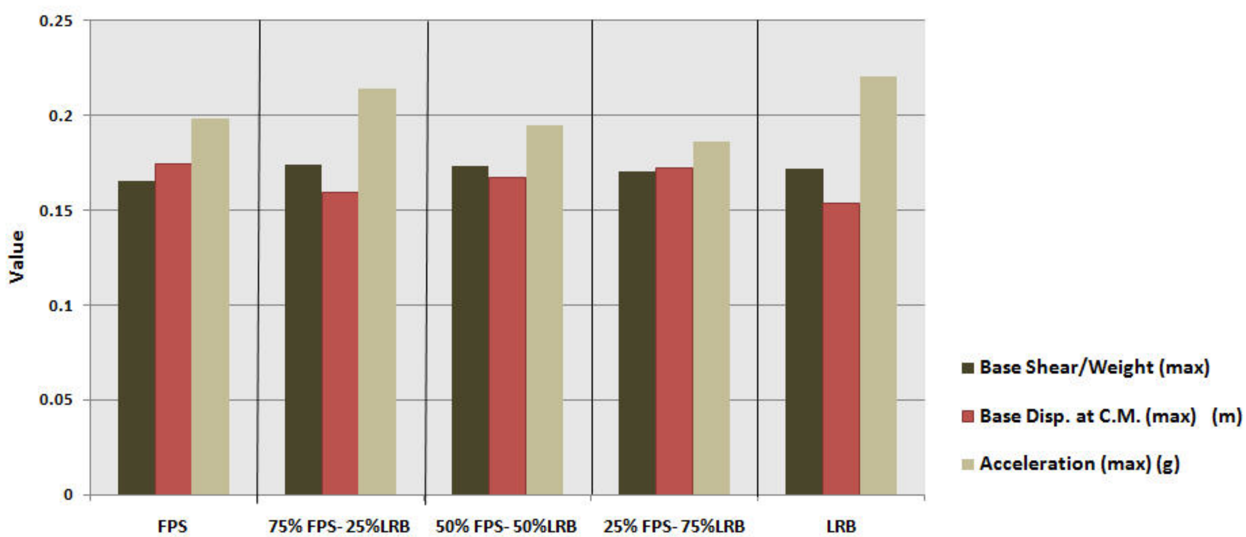

Figure 7. Response comparison of different models.

Table 4. Response reduction of models relative to control model under Manjil earthquake.

Response Decrease (%) Relative to Control Model				
TYPE	**75% FPS- 25%LRB**	**50% FPS- 50%LRB**	**25% FPS- 75%LRB**	**LRB**
Base Shear/Weight (max)	-5.29902	-5.07606	-3.08573	-4.10478
Base Disp. at C.M. (max) (m)	8.82521	4.41261	1.26074	11.86246
Acceleration (max) (g)	-7.86632	1.79949	6.06684	-11.41388

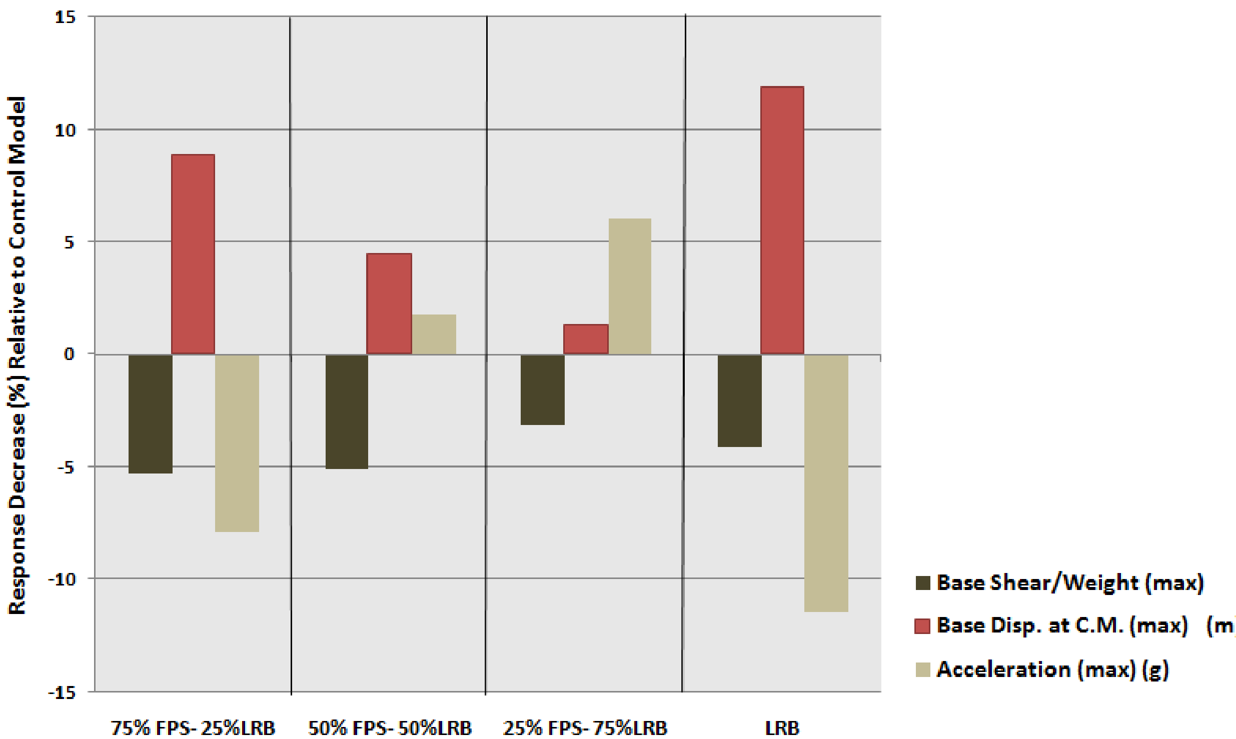

Figure 8. Response reduction of different models relative to control model.

Comparison of Seismic Responses of Different Models under Elcentro Earthquake

Figures 9 to 13 show the hysteretic responses of all five models. Similar to models under Manjil earthquake, the energy dissipation of models with FPS ratio equal to 0 and 25% are the best among all models. Maximum amounts of responses (maximum base shear to weight of superstructure, maximum base displacement at center of mass and maximum acceleration) for different models under Elcentro earthquake is summarized in Table 5. The bar chart of Figure 14 presents a comparison of numerical results of models under Elcentro earthquake. By examination of the bar chart, it is obvious that the least acceleration of superstructure is occurred in model with 25% of FPS Isolators. By considering the responses of control model as the base values, the decrease and increase of other models responses are calculated and summarized in Table 6 which also can be seen in Figure 15. The maximum decrease in acceleration has been occurred in model with FPS ratio of 25% by about 2 percent while the base displacement is increased by about 1 percent. In contrast, the base displacement of other models has been increased.

By considering the same principal parameters investigated for models under Manjil earthquake (reduction of acceleration in superstructure and energy dissipation capability of system), it is worth to conclude that the model with FPS ratio of 25% shows the best structural behavior against earthquake event of Elcentro earthquake.

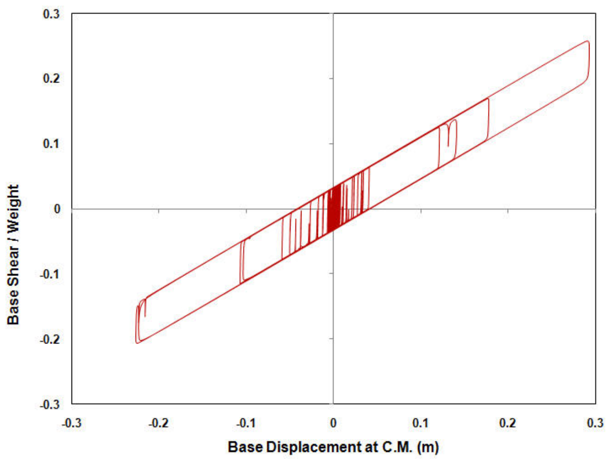

Figure 9. Hysteretic response of model FPS ratio of 100%.

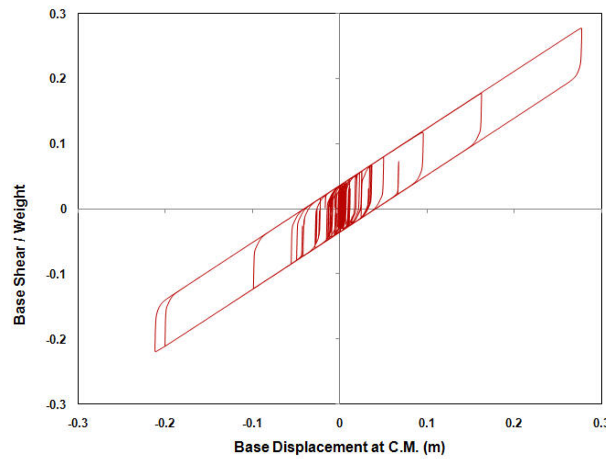

Figure 10. Hysteretic response of model FPS ratio of 75%.

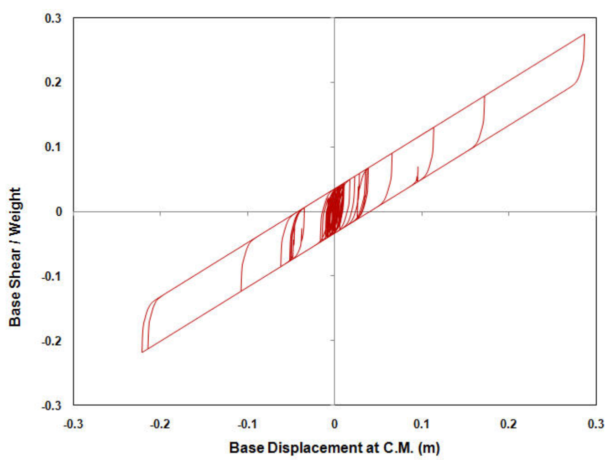

Figure 11. Hysteretic response of model FPS ratio of 50%.

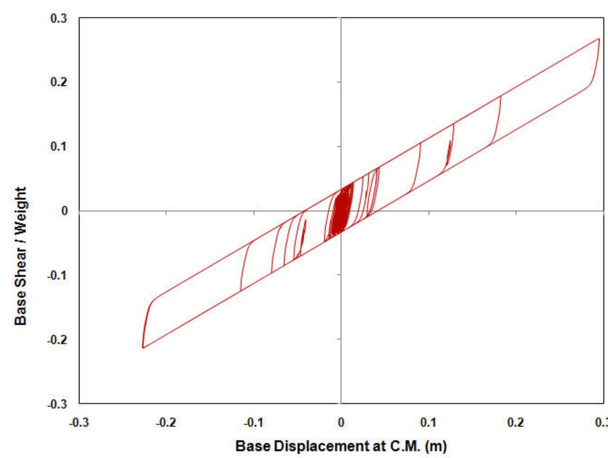

Figure 12. Hysteretic response of model FPS ratio of 25%.

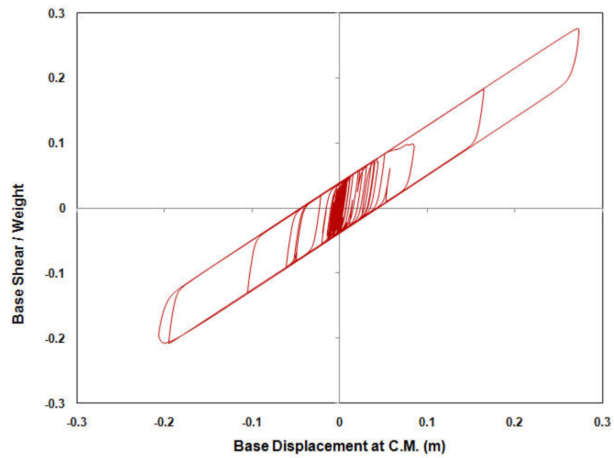

Figure 13. Hysteretic response of model LRB ratio of 100%.

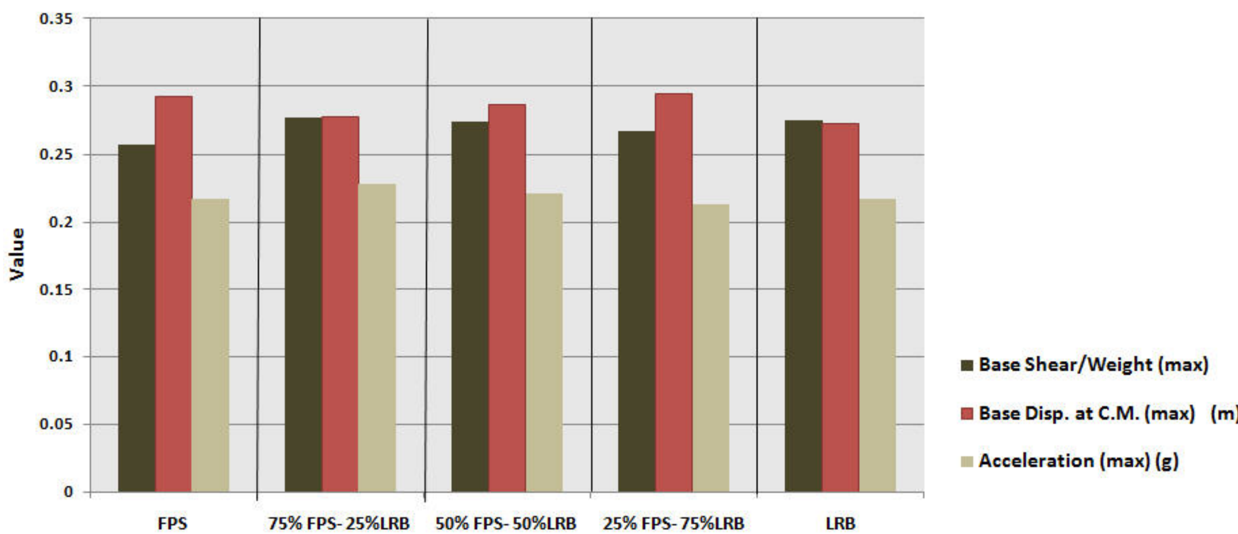

Figure 14. Response comparison of different models.

Table 5. Maximum responses of different structural models under Elcentro earthquake.

TYPE	Base Shear/Weight (max)	Base Disp. at C.M. (max) (m)	Acceleration (max) (g)
FPS	0.2577	0.2932	0.2177
75% FPS- 25%LRB	0.2773	0.2777	0.2284
50% FPS- 50%LRB	0.2742	0.2872	0.2215
25% FPS- 75%LRB	0.2677	0.2951	0.2131
LRB	0.2755	0.2728	0.2175

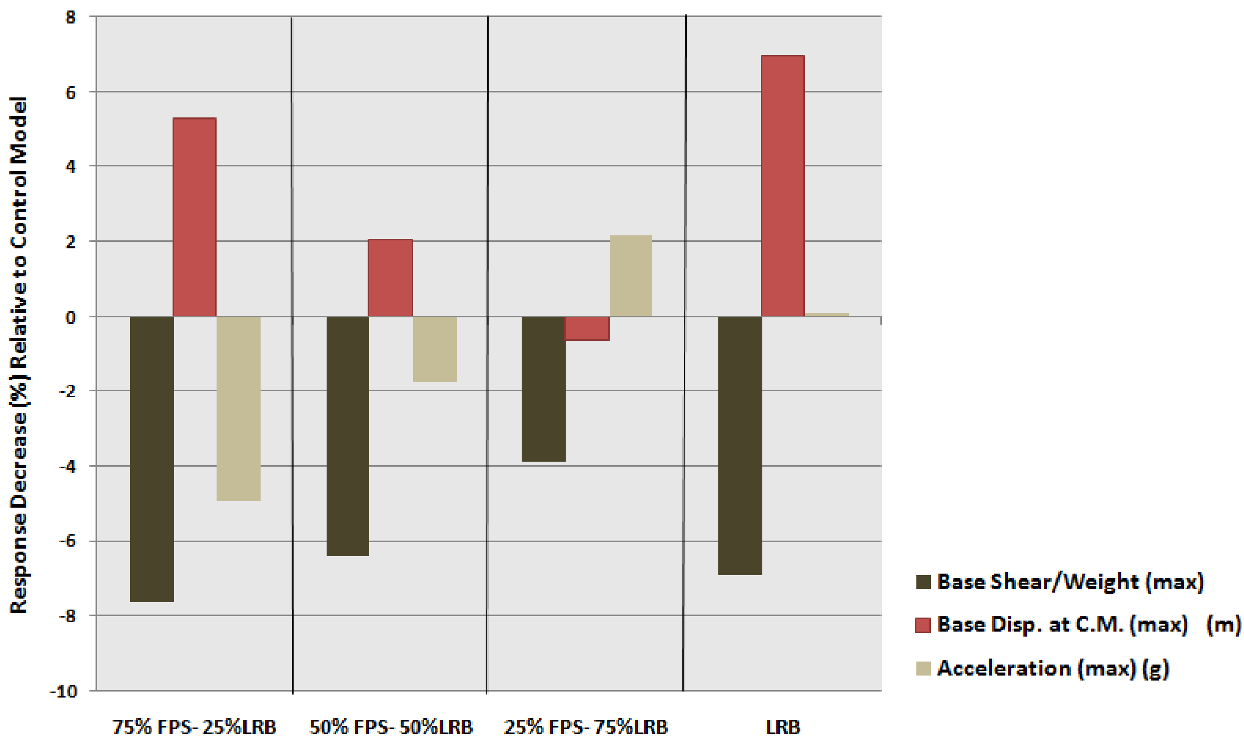

Figure 15. Response reduction of different models relative to control model.

Table 6. Response reduction of models relative to control model under Elcentro earthquake.

Response Decrease (%) Relative to Control Model				
TYPE	**75% FPS- 25%LRB**	**50% FPS- 50%LRB**	**25% FPS- 75%LRB**	**LRB**
Base Shear/Weight (max)	-7.61626	-6.38979	-3.86484	-6.90454
Base Disp. at C.M. (max) (m)	5.28649	2.04638	-0.64802	6.95771
Acceleration (max) (g)	-4.91573	-1.73221	2.15356	0.09363

Conclusions

Numerical results from the models under Elcentro and Manjil earthquakes reveal that the energy dissipation capability of models with FPS ratio equal to 25% is the best compared to all other models. Also the least accelerations of superstructures under both earthquakes have been occurred in models with 25% of FPS isolators. The maximum decreases in acceleration for models with FPS ratio of 25% relative to control model are about 6% and 2% respectively for Manjil and Elcentro Earthquakes; this shows that the optimized base isolation system has been more effective on decreasing the acceleration under Manjil earthquake. Since reduction of acceleration in superstructure and energy dissipation capability of system are two principle and substantial parameters in selection of isolation systems, by considering the hysteresis loops and the bar charts it can be concluded that the models with FPS ratio of 25% show the best structural behavior against earthquake events of Elcentro and Manjil.

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