Proposing the Optimized Combination of Different Isolation Bearings Subjected to Near-Fault Ground Motions

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SUMMARY:
Recent earthquakes have illustrated significant difference between seismic responses of structures in the vicinity of causative earthquake faults and those observed further away from the seismic source. Seismologists have identified forward directivity and fling effects as the primary characteristics of near-fault ground motions. It has been observed that the near-fault ground motions with forward rupture directivity are characterized by a large pulse. These pulse-type motions can place severe demands on structures in the near-fault region. Seismic base isolation is an earthquake resistant design method that is based on decreasing the seismic demand instead of increasing the seismic capacity. Isolators can be widely classified as sliding and elastomeric. It is very essential to provide an optimized arrangement of different types of isolators in the structure since it affects the structural responses to earthquakes. This paper compares sliding versus elastomeric seismic isolation of a typical building under near fault ground motions to enhance the understanding of their unique impacts on building response. A seismic evaluation of the building, isolated in one case with the sliding isolators and in another case with the elastomeric isolators and three cases with combination of both types, is performed using a nonlinear analytical model.

Keywords: Near-Fault, Ground Motions, Base Isolation, LRB, FPS.

1. INTRODUCTION

Ground motions close to a ruptured fault can be considerably different than those observed further away from the seismic source. Forward directivity and fling effects have been identified by the seismologists as the primary characteristics of near fault ground motions (Mavroeidis and Papageorgiou, 2003). These characteristics of ground motion near the fault of major earthquakes contain large displacement and velocity pulses. The estimation of seismic response of base-isolated structures for a project site close to an active fault should account for these special aspects of near fault ground motions. 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 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, Kelly 2003, Sharbatdar et al. 2011).

In this paper a combination system consist of both LRB and FPS isolators has been investigated and the optimized system has been evaluated under near fault ground. A seismic evaluation of the building, isolated in one case with the sliding isolators and in another case with the elastomeric isolators and two cases with combination of both types, is performed using a nonlinear analytical model. The comparison between hysteretic responses of models as a main criterion for energy dissipation of system has been investigated and evaluated.

2. NUMERICAL MODELS

Structural models prepared for analysis include 15-story buildings. 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.

Nonlinear analytical modeling techniques (Nagarajaiah et al. 1991, Tsopelas et al. 2005) were used for dynamic analysis of structural models. 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 3 records of near fault ground motions. Three earthquake events selected as near source ground motions: the 1994 Northridge, the 1979 Coyote Lake and the 1979 Imperial Valley earthquakes (Figures 2, 3 and 4). These records contain strong velocity and displacement pulses of relatively long periods which distinguish them from typical far field earthquakes. The characteristics of earthquakes and the convergence procedures of modal parameters are presented in Tables 2.1 and 2.2 respectively.

Following assumptions are made for the structural system under consideration: The effects of soil–structure interaction are not taken into consideration, The columns are inextensible and weightless providing the lateral stiffness, The floors are assumed rigid in its own plane and the mass is supposed to be lumped at each floor level, The system is subjected to single horizontal component of the earthquake ground motion.

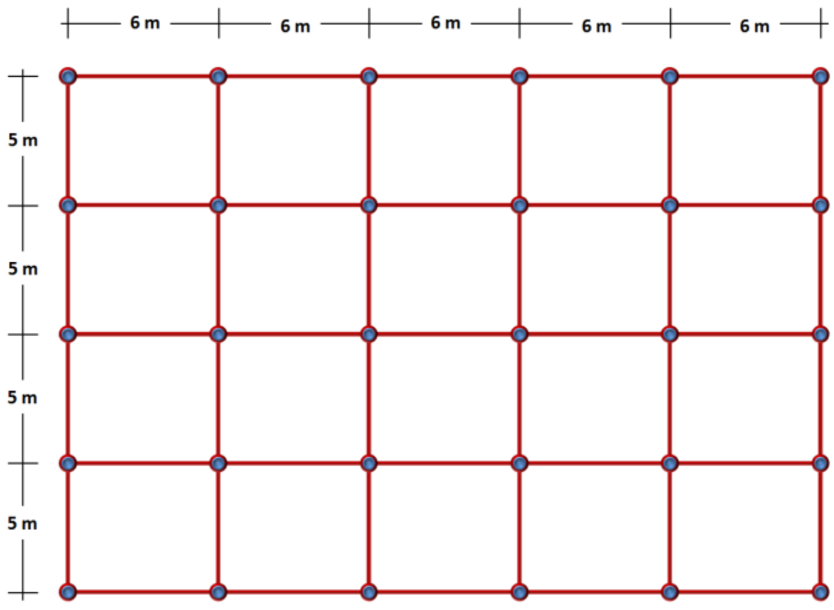

Figure 1. Typical plan

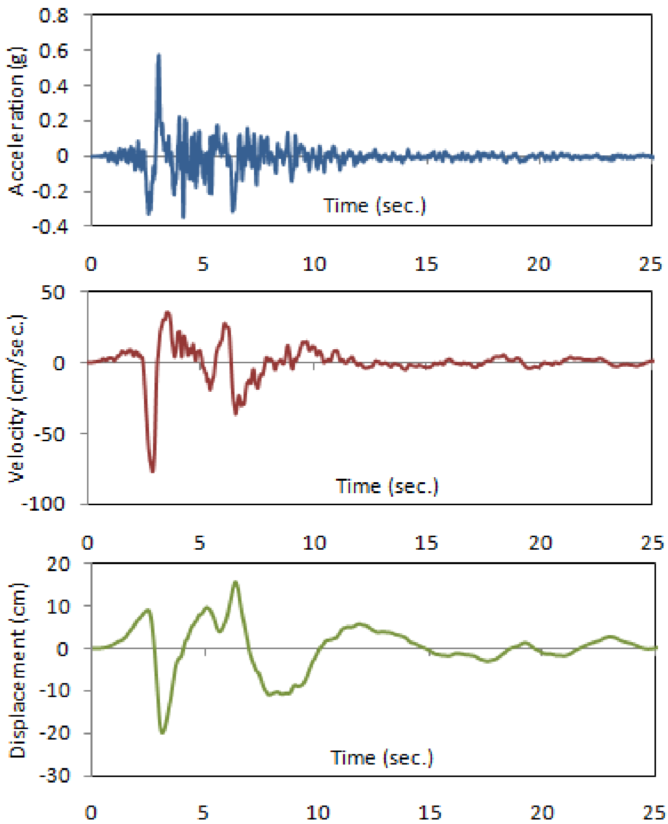

Figure 2. Time history components of full record and equivalent pulse. Records obtained from the 1994 Northridge earthquake NGA database.

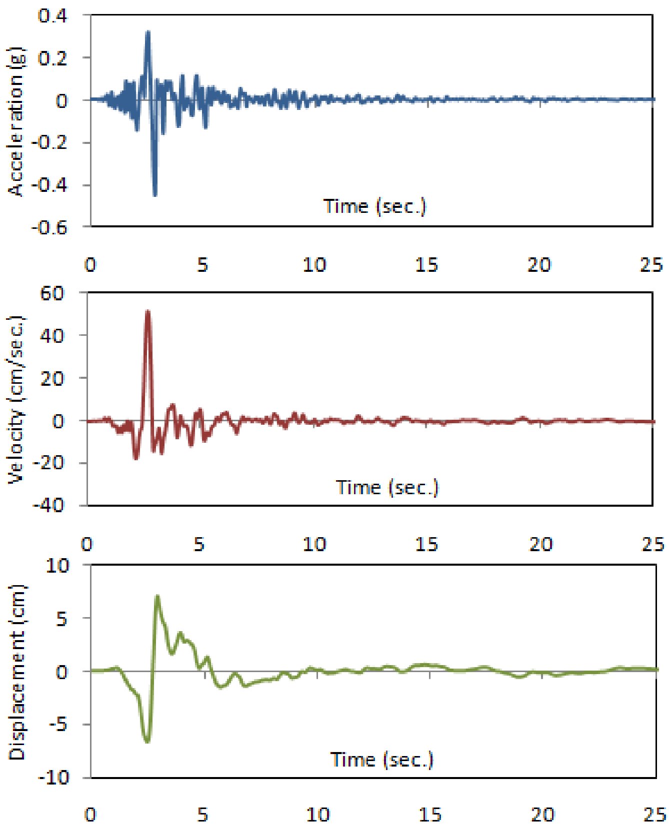

Figure 3. Time history components of full record and equivalent pulse. Records obtained from the 1979 Coyote Lake earthquake NGA database.

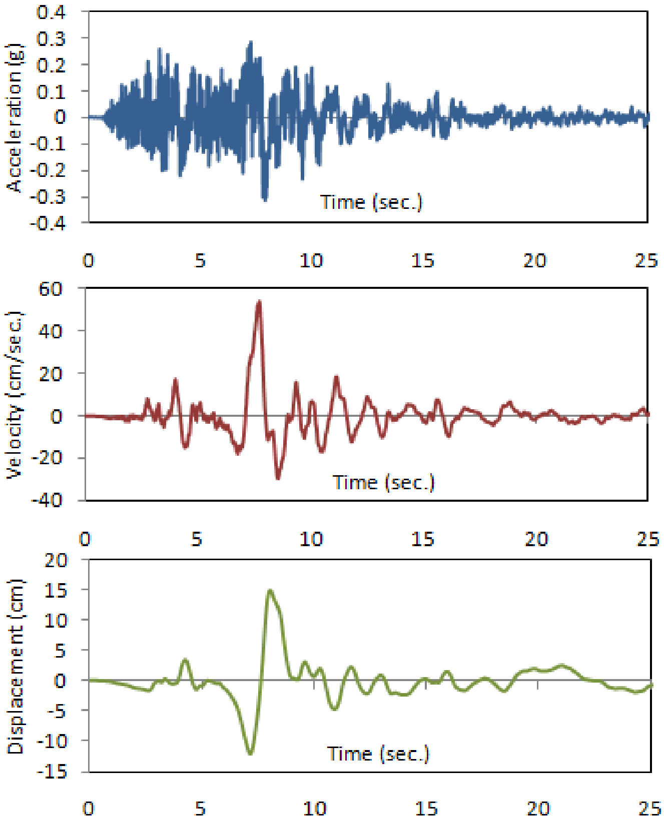

Figure 4. Time history components of full record and equivalent pulse. Records obtained from the 1979 Imperial Valley earthquake NGA database.

Table 2.1. Characteristics of earthquakes used for analysis

Event	Year	M_w	Station	Closest to Fault Rupture (km)	PGA (g)	PGV (cm/sec)	PGD (cm)
Northridge-01	1994	6.69	LA Dam	5.92	0.57	77.1	20.11
Coyote Lake	1979	5.74	Gilroy Array #6	3.11	0.45	51.54	7.1
Imperial Valley-06	1979	6.53	Agrarias	0.65	0.31	53.79	14.85

Table 2.2. 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	9749.04	378.81	380.73	8218.44	82184.4	0.00463	387.95
2	0.24874	9749.04	378.81	387.95	8189.4	81894	0.00474	388.12
2	0.24874	9749.04	378.81	388.12	8188.73	81887.3	0.00474	388.12

3. RESULTS

The analytical results are presented and evaluated for each type of distribution of isolators in this section. The first model includes 15-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. By considering 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 is summarized in Tables 3.1, 3.3 and 3.5; these responses include maximum base shear to weight of superstructure, maximum base displacement at center of mass and maximum acceleration. By examination of the results, 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 3.2, 3.4 and 3.6. The negative values in the tables refer to increase in response relative to control model.

The maximum decrease in acceleration under the record of LA Dam station of 1994 Northridge earthquake has been occurred in model with FPS ratio of 25% by about 3.25 percent while its decrease in base displacement is about 1.4 percent which is the least amount among all models.

Similar to models under Northridge earthquake, the maximum decrease in acceleration under Gilroy Array #6 record of 1979 Coyote Lake earthquake has been occurred in model with FPS ratio of 25% by about 1.5 percent while the base displacement is increased by about 4 percent. In contrast, the base displacement of other models has been increased. Also The maximum decrease in acceleration under the record of Agrarias station of 1979 Imperial Valley earthquake has been occurred in model with FPS ratio of 25% by about 4.6 percent while its decrease in base displacement is about 0.6 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 hysteresis loops and the results it can be concluded that the model with FPS ratio of 25% shows the best structural behaviour against earthquake events.

Table 3.1. Maximum responses of different structural models under Northridge earthquake.

TYPE	Base Shear/Weight (max)	Base Disp. at C.M. (max) (cm)	Acceleration (max) (g)
FPS	0.1375	13.45	0.492
75% FPS- 25%LRB	0.1452	12.63	0.503
50% FPS- 50%LRB	0.1446	12.82	0.487
25% FPS- 75%LRB	0.1415	13.26	0.476
LRB	0.1434	12.29	0.531

Table 3.2. Response reduction of models relative to control model under Northridge 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)	-5.600	-5.164	-2.909	-4.291
Base Disp. at C.M. (max) (m)	6.097	4.684	1.413	8.625
Acceleration (max) (g)	-2.236	1.016	3.252	-7.927

Table 3.3. Maximum responses of different structural models under Coyote Lake earthquake.

TYPE	Base Shear/Weight (max)	Base Disp. at C.M. (max) (cm)	Acceleration (max) (g)
FPS	0.0762	4.88	0.4657
75% FPS- 25%LRB	0.0769	4.85	0.4723
50% FPS- 50%LRB	0.0772	4.94	0.4694
25% FPS- 75%LRB	0.0764	5.08	0.4588
LRB	0.0781	4.76	0.4652

Table 3.4. Response reduction of models relative to control model under Coyote Lake 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)	-0.919	-1.312	-0.262	-2.493
Base Disp. at C.M. (max) (m)	0.615	-1.230	-4.098	2.459
Acceleration (max) (g)	-1.417	-0.795	1.482	0.107

Table 3.5. Maximum responses of different structural models under Imperial Valley earthquake.

TYPE	Base Shear/Weight (max)	Base Disp. at C.M. (max) (cm)	Acceleration (max) (g)
FPS	0.1012	8.33	0.3567
75% FPS- 25%LRB	0.1061	8.02	0.3585
50% FPS- 50%LRB	0.1052	8.16	0.3545
25% FPS- 75%LRB	0.1035	8.35	0.3402
LRB	0.1058	7.91	0.3635

Table 3.6. Response reduction of models relative to control model under Imperial Valley 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)	-4.842	3.721	-0.505	-4.842
Base Disp. at C.M. (max) (m)	-3.953	2.041	0.617	-3.953
Acceleration (max) (g)	-2.273	-0.240	4.626	-2.273

4. CONCLUSION

A seismic evaluation of the building, isolated in one case with the sliding isolators and in another case with the elastomeric isolators and three cases with combination of both types, is performed using a nonlinear analytical model. Analytical results from the models 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 selected near fault ground motions records 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 3.25, 1.5% and 4.6% respectively for Northridge, Coyote Lake and Imperial Valley Earthquakes; this shows that the optimized base isolation system has been more effective on decreasing the acceleration under Imperial Valley 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 energy dissipation of systems it can be concluded that the models with FPS ratio of 25% show the best structural behavior.

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