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Seismic Performance of Elastomeric and Sliding Friction Isolation System

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Abstract

The base isolation technique is widely used in the isolation of structures for providing efficient protection to structures concerning different loadings. This study aims to evaluate comparative performance and inelastic responses of the base-isolated structure for two types of isolation systems under the Far-field and Near-field earthquake. For this purpose, seismic response quantities like base shear, peak floor displacement, absolute acceleration, and isolator displacement for ten-story reinforced concrete building frame base isolated by lead rubber bearings (LRBs) are evaluated and compared with the seismic response of the same structure base isolated by Friction Pendulum Bearing Isolator. Nonlinear time history analysis is carried out to investigate the inelastic behavior of the base-isolated structure. The building frame was designed according to IS1893:2016 seismic code and IS 456:2000. To represent a wide range of assessments, a 10 storey building frame taking identical isolation parameters for elastomeric and sliding isolation system was analyzed in SAP 2000. It was observed that the responses of both the isolation system are nearly the same for all the three earthquakes.

Keywords: Seismic performance, responses, LRB, FPS, Non-linear time history analysis.

1. Introduction

The technique of Base isolation is the most effective, well-accepted strategy for the protection of structure during earthquake events. This strategy is widely accepted and implemented in a few codes for the design base-isolated building. In this technique, a flexible layer is inserted between the foundation and superstructure which decouples the structure from the damaging action of ground motion. The goals of the base isolation are 1. Shifts the fundamental period of a structure to a long period to prevent the structure from damage 2. Absorbs the full displacement demand induced by seismic ground motions at the isolation layer. Since many base isolation devices were developed which results in an increase in the effectiveness of base isolation technique (Kelly et al. 2010). BIS can be grouped into two parts, namely, the sliding systems and elastomeric bearings. There are three types of elastomeric bearings which are laminated rubber bearing, lead rubber bearing, and high damping rubber bearing (1). Apart from the other BIS, the FPS is the most widely used BIS because of its simple design, Lower thickness, and durability, hysteretic behavior.
The three important features common to the isolation devices such as HDRB (High Damping rubber bearings, friction bearings, and LRB are flexibility in the horizontal direction, shifts the fundamental vibration period of the dissipation capacity, reduces the displacement demand, and higher stiffness at small displacement also limits movements due to earthquake loadings and wind loadings. Many researchers have studied the seismic behavior of base-isolated buildings. The base-isolated building behavior is different under different (far-field and near field) earthquakes. When base-isolated buildings are excited by near-field earthquakes causes severe damage because of high energy pulses as compared to far-field earthquakes. Near field, earthquakes result in high isolator displacement which can cause the failure of isolated structures (12).
In this paper near field with two effects and far-field earthquake, records are considered for time history analysis of 10 storey building frame base isolated by elastomeric bearing and sliding isolation system. In recent years more attention has been growing towards the effects of near-fault earthquakes on reinforced concrete (r.c.) base-isolated structures. Horizontal velocity pulses having long duration and high amplitude are expected at sites that are near to an active fault, producing a prominent displacement of the base isolation system and an increase of inelastic demand in the superstructure (2). The effects of variability of mechanical properties in elastomeric and sliding bearings were quantified on the nonlinear seismic response of base-isolated r.c. framed structures. Complex interdependence of the coefficient of friction, axial pressure, sliding velocity, and the temperature was presented for implementation in the nonlinear response-history analysis (4). The seismic

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reliability of a structure which is base-isolated by single-concave FP isolators was evaluated considering design characteristics and isolator properties as random variables (10). For the structure's base-isolated with friction pendulum isolation systems, a comparison was done for the different modeling approaches for the simulation of the seismic response. Several parameters like axial load and friction coefficient strongly affect the behavior of these systems (5). Non-linear dynamic analysis of a six-story R.C framed building was carried out and designed twelve base-isolated test structures. Lateral stiffness and the variation of frictional force of the FP system induces torsion with residual displacement and uplift during the sliding phase was also investigated (6). For friction pendulum bearing (FPB) influence of the isolator, characteristics were examined on the non-linear response of the buildings under various seismic excitations (7). Seismic capacity and performance for LRB-isolated frame buildings located on the NF site area were investigated (8). The mechanical model was proposed for predicting the behavior of elastomeric seismic isolation bearings subjected to combined end rotations and shear deformation.

2. Theory

Ten storey R.C building frame is taken for analysis and designed for different loads gravity loads and seismic Loads concerning the IS 1893. An analysis is carried out first for the fixed base structure and after that building, frame base isolated by Elastomeric and sliding isolation system for a set of ground Motions. Ground motion records (Far-field and near field with two effects) are considered to investigate the seismic behavior of the building frame. There are two effects of Near-field earthquakes 1. directivity effect 2. fling-step effect which is based on rupture mechanism, residual ground displacement, and slip direction of rupture. when the velocity of the rupture of fault is very near to velocity of the shear wave at the site and If the rupture direction is aligned towards the site, this effect is known as the directivity effect (12). Tectonic deformation causes the permanent displacement of ground in the Fling-step effect. In this paper results of building frame base isolated by the lead rubber bearing (LRB) are compared with the frame base isolated by Friction Pendulum Bearings. Additional dissipation of energy is provided by the rubber core by increasing the size of the hysteresis loop. Shear deformation takes place in lead plug under the action of horizontal loads.

A typical idealized force-displacement relationship of lead–rubber bearing is shown in fig. (a) and the Idealized force-displacement graph of FP bearing is shown in fig (b).

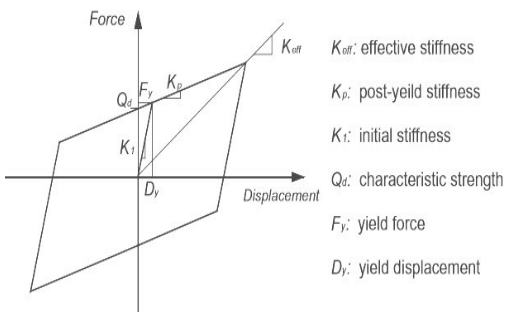

Fig.(a) force-displacement relationship of lead rubber bearing

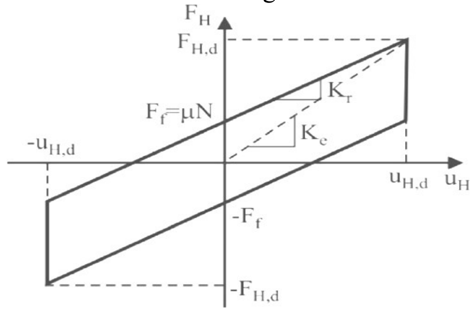

Fig (b) Idealized force-displacement Graph of FP isolation system

3. Numerical Study

In the present paper seismic responses are investigated for a 10 storey building frame subjected to ground motions i.e Near field (both effects) and far-field earthquakes. Seismic response in terms of base shear, peak top floor displacement, first-floor displacement absolute acceleration, and maximum storey drift and isolator displacement, plastic hinges are evaluated for fixed base structure and structures with base isolation. Ground motion records are taken from PEER Strong Motion Database website. All the records have been normalized to 0.4g. The details of the earthquake records like magnitude, PGA, PGD, PGV are given in table no. 1

Base Isolators are designed to take reference of the method proposed in T.K. Datta (11). By taking identical properties for LRB AND FPS, NLTHA is carried out. Details of isolator properties and Building are given in tables 2 and 3.

Table 1: Ground Motion Records from PEER strong motion database

S.No.	Year	Earthquake	Magnitude	Station	Component	Peak Ground Acceleration(g)	Peak Ground Velocity (cm/s)	Peak Ground Disp. (cm)
FAR FIELD EARTHQUAKE RECORDS								
1	1978	TABAS	7.4	FERDOWS	L	0.093	5.4	2.24
2	1992	Landers	7.3	COOL WATER	TR	0.417	43.419	15.25
NEAR FIELD EARTHQUAKE RECORDS (FORWARD DIRECTIVITY EFFECT)								
3	2003	BAM	6.6	BAM	L	0.8	124.1	33.94
4	1992	ERZINKAN	6.69	ERZINKAN	EW	0.5	78.15	28.03
NEAR FIELD EARTHQUAKE RECORDS (FLING STEP EFFECT)								
1	1999	Chi-Chi	7.6	TCU 052	E	0.35	151.20	210.44
2	1999	Chi-Chi	7.62	TCU068	N	0.37	264.09	421.67

Table 2: Isolator Proprieties

Isolator Properties		
1	Post Yield Stiffness (K_D)	949 KN/M
2	Characteristic Strength of Bearing (Q_D)	28.82 KN
3	Effective Stiffness (K_{eff})	1126 KN/M
4	Yield Strength (F_Y) $F_Y = Q_D + K_D D_Y$	31.94 KN
5	Initial Stiffness (K_e) $K_e = F_Y/D_Y$	9490 KN/M
6	Stiffness ratio post yield (α) $\alpha = K_D/K_e$	0.1
7	Vertical stiffness of Bearing	267474 KN/M
8	Radius of Curvature (R)	1.19 M
9	Fast dynamic friction coefficient (μfast)	0.04

Table 3: Details of Building

1	NO. of Storey	10
2	X Direction -No. of bays	4
3	Y Direction -NO. of Bays	6
4	Floor to floor Height	3 m
5	Height of Parapet	1 m
6	Thickness of slab	120 mm
7	The thickness of the Brick Wall	230 mm
8	Concrete Grade	M40
9	Steel Grade	Fe415
10	Concrete Density	25 kN/m^3
11	Brick Density	20 kN/m^3
12	C/S of column	600 X 600 mm
13	C/S of Beam	300 X 600 mm
14	Water Proofing Terrace	1.5 kN/m^2
15	F.F load	1 kN/m^2
16	L.L on floors	2 kN/m^2
17	L.L on Roof	1.5 kN/m^2
18	Seismic Design Code	IS1893
19	Seismic Zone	V
20	Type of Building Frame	SMRF
21	Importance Factor (I)	1
22	Type of Soil	Medium

In this paper Non-linear time history analysis is done to investigate the seismic behavior of the building. Comparative performance of Lead rubber bearing and friction pendulum bearing taking identical isolator properties is evaluated and results are compared with that are obtained from a fixed base structure as shown in table no. 4. Response quantities are scaled to PGA = 0.4 g.

A comparative study is carried out for the response parameters for two types of extreme level earthquakes.

The Force and displacement graph of LRB and FPS isolators are shown in fig. c-f. We get different force-displacement characteristics for extreme level earthquakes (Far-field and near field). We can see from the figure that for far-field earthquakes we get closely spaced cycles of isolator displacement. For near field earthquakes, it was observed that no. of loops are less and isolator displacement is much larger as compared to isolator displacement of far-field earthquakes.

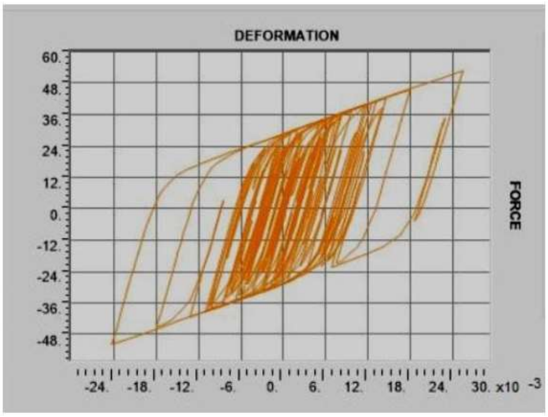

fig.c Force displacement graph for rubber isolator Tabas earthquake

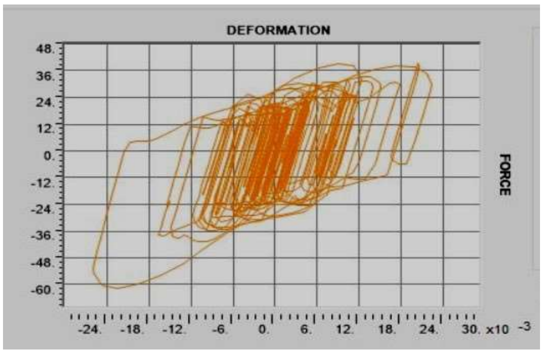

fig.d Force displacement graph for Friction Pendulum Bearing tabas earthquake

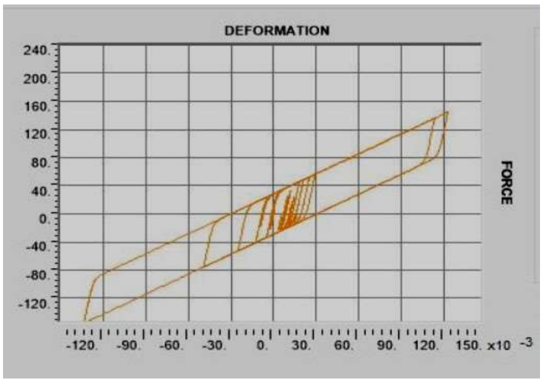

fig.e Force displacement graph for Rubber Bearing Erzinkan earthquake

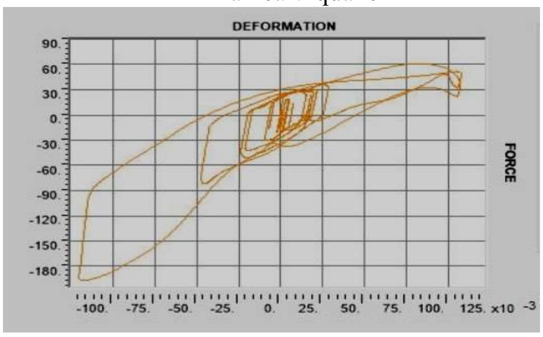

fig.f Force displacement graph for Friction Pendulum isolator Erzinkan earthquake

4. Results andDiscussion

Response quantities are evaluated for a 10 storey building frame for fixed base and base-isolated by Lead rubber bearing and Friction pendulum system. Time history analysis Results obtained for the fixed-base building frame are compared with the results of the base-isolated frame. From the table 4, we can observe that percentage reduction in base shear for LRB AND FPS for far-field earthquake ranges between 67 – 78 % while for the fling step with directivity effect reduction is considerable which is 31-42 % and base shear are significantly reduced to 1-15% for the fling step effect. Reduction in Top storey absolute acceleration for far-field records and near field records is above 50% whereas for near field earthquake it is below 50 %. If we compare isolator displacement for near field earthquakes and far-field earthquake, there is an increase in isolator displacement for near field earthquake. We can observe from the figure c to f that isolator displacement will be nearly the same for LRB and FPS. Base isolation is effective in reducing storey drift 70-85 % for a far-field earthquake.

Table 4: Response parameters of a fixed base and base-isolated building excited by far-field earthquakes and near field earthquakes.

EARTHQUAKE	BUILDING TYPE	BASE SHEAR IN KN	TOP STOREY ABS ACC M/S^2	MAX. STOREY DRIFT	PEAK TOP FLOOR DISPLACEMENT MM	PEAK FIRST FLOOR DISP. MM	ISOLATOR DISP. MM	NO. OF HINGES
TABAS	FB	1192	5.8	2.53	54.39	3.8		68
	BI-RUBBER	263	2.4	0.66	39.92	26.95	25.2	4
	BI- FPS	271	2.2	0.71	43.34	27.93	26.4	4
% REDUCTION LRB		77.94	58.62	73.91	26.60			
% REDUCTION-FPS		77.27	62.07	71.94	20.32			
LANDER	FB	1441	5.8	7.9	136.5	8.4		78
	BI-RUBBER	463	2.2	1.1	90.29	71.11	69	8
	BI- FPS	436	2.5	1.1	87.16	64.74	61.5	11
%REDUCTION LRB		67.87	62.07	86.08	33.85			
%REDUCTION-FPS		69.74	56.90	86.08	36.15			
Near Field Earthquake (Directivity Effect)								
BAM	FB	1303	5.99	6.56	113.28	89.78		70
	BI-RUBBER	894	2.72	5.3	224.31	177.21	160	51
	BI- FPS	863	2.43	5.15	208.86	163.67	150	50
%REDUCTION LRB		31.39	54.59	19.21	98.01			
%REDUCTION-FPS		33.77	59.43	21.49	84.38			
ERZINKAN	FB	1217	7.29	5.82	101.06	11.3		72
	BI-RUBBER	768	1.93	2.99	175.28	142.5	132	34
	BI- FPS	715	1.87	2.45	157.1	127.83	120	18
%REDUCTION LRB		36.89	73.53	48.63	73.44			
%REDUCTION-FPS		41.25	74.35	57.90	55.45			
Near Field Earthquake (FLING STEP Effect)								
chi chi 052 E	FB	1419	5.46	19.96	362.1	47.74		96
	BI-RUBBER	1398	3.04	49.26	742.39	323.97	264	113
	BI- FPS	1365	3.08	40.8	747.91	327.15	250	126
%REDUCTION LRB		1.48	44.32	59.48	51.23			
%REDUCTION-FPS		3.81	43.59	51.08	51.59			
chi chi 068 ns	FB	1297	5.5	10.65	181.56	24.62		74
	BI-RUBBER	1143	2.8	34.2	597.08	304.72	210	101
	BI- FPS	1092	2.75	30.07	571.54	294.12	210	101
%REDUCTION LRB		11.87	49.09	68.86	69.59			
%REDUCTION-FPS		15.81	50.00	64.58	68.23			

Plastic hinge formation shows the inelastic performance of the building frame. It has been observed that no. of hinges developed for Tabas and Lander earthquake are only 4 and 8 for LRB and FPS hinges are 4 and 11, so for both the earthquakes no. of plastic hinges are very less which shows minimum damage to the structure. Maximum numbers of hinges are formed for near field earthquakes (fling step effect), which can cause severe damage. No. of hinges formed for near field records with directivity effect is considerably less showing minimum damage when compared with structures subjected to the fling step effect. For far-field earthquakes as we can see from fig. c and d number of loops formed are large and the curve is much wide indicating a large amount of energy dissipation for both the isolators. Less number of loops are formed for the frame subjected to near field earthquake (directivity effect) as shown in fig. e and f indicating less dissipation of energy for the r.c. building frame with base isolation subjected to far-field records.

5. Conclusion

Non-linear time history analysis is performed to evaluate the seismic response of a 10 storey building frame for fixed base and base-isolated by LRB and FPS taking identical isolation parameters for the far-field and near field, earthquakes records scaled to PGA 0.4g. Different response quantities are compared for these earthquakes for a fixed base and base-isolated by two isolators from which the following conclusions can bedrawn:

1. Taking identical isolator properties reduction in response quantities are nearly the same for both the isolation systems.
2. For the building with base isolation, there is a reduction in the base shear and maximum storey drift values due to the higher time period resulting in lower acceleration acting on thestructures.
3. The maximum displacement of isolator much increases for near-field extreme level earthquakes when compared with far-field earthquakes which cause base isolation inappropriate which causes failure of the base-isolated structure.References

Disclosures

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