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PARAMETRIC STUDIES ON THE COMPARISON OF THE BEHAVIOUR OF STRUCTURES WITH DIFFERENT BASE ISOLATION SYSTEMS

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Abstract

In this study, base isolated 2D buildings were modelled and the effects of the different isolation systems on structures with different number of stories were investigated. The structures were also modelled as a fixed based structure. A nonlinear time history analysis was performed. Different severe earthquake records were used in the structural analysis. The results of the study show that the isolation systems are more effective in reducing the effects of the earthquakes. The results of the parametric studies are presented in this study.

Keywords: Earthquake resistant design, Base isolation systems, Time history analysis.

1. Introduction

As long as more information is obtained about the nature and forces acting on structures of earthquake, more durable buildings are needed with the aim of improving safety. During the Earthquake, when the period of the building and the period of the ground get close to each other, due to the entry into resonance of structure, the earthquake damage could be much higher than expected. In general there are important stages to make earthquake-resistant building such as Long-period structures to build on short period substrates and short-period structures to build on long period grounds.

One of the protection measures against to effects of the earthquake is to make seismic base isolation at buildings [1]. The definition of this topic which is currently discussed today is quite old. However, the emergence of application oriented to technology is counted new.

The notion of base isolation systems is pretty easy [2]. During an earthquake, a transaction occurs on earth. This event spreads to every direction in the form of a wave. When the movement reaches the foundation of a structure, foundation begins to shake [1]. After that, foundations shake the carrier system which is connected to themselves and effects of the inertia forces occur at sections of system compounds. Namely, seismic isolation separates the basis of the structure from the carrier system and prevents access of vibration to the structure. This creates the main idea of the base isolation.

Base isolator which is one of the accepted seismic protection systems is applied greatly around the world. The system separates the buildings or structures that have been exposed to ground motion by inserting a component which has low horizontal stiffness [2]. This implementation brings the structure lower essential frequency than fixed-base and prevalent ground motion frequencies. Thus, the base shear force of structure and relative accelerations and displacements of floors reduce satisfied.

Even though seismic isolation systems have effective design implementations, in terms of reacting the earthquake loads, this technic may not suitable for all buildings and at all grounds [3]. Usually, this practice is more common at low-and medium-rise buildings. Because their active period ranges include the range of dominant period of many earthquake. As regards to ground, soft soil is not suitable for seismic isolation but stiff soil is better for working of seismic isolation efficiently [3]. As well as, adjacent structures is not appropriate for being applied seismic isolation.

There are a wide variety of isolation bearings. These are Laminated Rubber Bearings, Sliding bearings, Electricite-de-France Bearings, Tass Bearings, Friction Pendulum Bearings and Helical Steel Springs. In addition, laminated rubber bearings have three kinds which are low damping rubber bearings, lead rubber bearings and high damping rubber bearings [4]. The most widely used isolation systems are elastomeric bearings which are mostly applied at bridges [1].

Since the design, material and testing costs of seismic isolation are high, it is usually applied for continuity of required facilities [5]. In terms of cost, addition of the base isolations to these facilities which are hospitals, immediate occupation units and any other important centers, are more suitable. Besides, Historical buildings such as mosques and churches can be retrofit or protect versus earthquake loads. Because non-structural elements and precision instruments which are used in these facilities should be protected. The performance of these devices can easily deteriorate even at low level of acceleration [6]. As a result, the base isolation aims reducing damage of structure components. Most of isolated building like hospitals in the United States contains structural or non-structural elements which are important, expensive and precious. [3]. For instance, in San Bernardino, the Foothill Communities Law and Justice Center was first applied by seismic isolation in the United States. This center was built by seismic isolation to resist an earthquake of 8.3 magnitude and had not got any damage when exposed to a 5.5 Richter magnitude. The first historic building in the United States, the Salt Lake City and County Building, was seismic isolated.

Also, San Francisco City hall, Oakland City Hall and Los Angeles City Hall, which were built in the first half of 1900s, have been implemented seismic isolation systems to mitigate seismic forces [3]. Apart from these, The USC University Hospital is the first seismic isolated building that has got experience against severe earthquakes.

Since base isolation is needed to reduce functional and potential losses at hospitals, this protection system will continue being used versus earthquake forces in the future [6].

The objective of this paper is to determine and evaluate performance of different number of stories 2D buildings by different base isolation types. In this study, fixed-base and isolated base hospitals are compared in terms of natural fundamental periods, floor acceleration and design base shear. In analyses, high damping rubber bearings (HDRB), lead rubber bearings (LRB) and friction pendulum systems (FPBs), which are the most popular base isolation systems in the world, are used [5]. However, this study could be expanded to varied isolation types and according to new parameters.

1.1 Models of Isolation Systems

There are two categories of isolation systems based on analysis, such as elastomeric bearings and sliding systems. The choice of isolation systems and analysis procedure must be done to predict the seismic response of different number of stories hospital buildings properly [3]. Nonlinear time-history analysis is suggested by guide specifications (NRCC 1995; BSSC 1997; ICBO 1997; AASHTO 1999). In the present study, three representative isolation systems were investigated and explained below.

The high damping rubber bearing (HDRB) is most commonly adopted base isolation system. HDRB has high-damping capacity, horizontal flexibility and high vertical stiffness. Although HDRB involve hysteretic dissipation of energy and nonlinear behavior, it may still be treated as linear, using equivalent stiffness and damping properties.

The second type of elastomeric bearing is lead-rubber bearings (LRB). This base isolation system provides the combined features of vertical load support, horizontal flexibility, restoring force and damping in a single unit. These bearings are similar to the HDRB except a central lead core is used to provide an additional means of energy dissipation. The LRB also provides energy absorbing capacity through additional hysteretic damping in yielding of the lead core that reduces the lateral displacements of the isolator, especially under ambient vibrations [1]. LRB isolation systems behaves bilinearly. Bilinear systems have a more efficient and reliable energy dissipation mechanism.

The last isolation system is friction pendulum bearing. One of the most popular and effective techniques for seismic isolation is in the use of the sliding isolation devices. It is also a widely preferred isolation system during the retrofitting works. The FPB develops a lateral force equal to the combination of the mobilized frictional force and the restoring force developed because of rising of the structure along the spherical concave surface. FPB systems is modeled as bilinearly like LRB isolation systems [3].

In this study HDRB, LRB and FPB isolation systems were analyzed by assuming parametric stiffness values. The initial elastic stiffness was approximately ten times and hundred times the post yield stiffness for LRB and FPB isolation systems. As well as, the same effective period, damping and displacement values were taken for parametric studies.

Table 1 – Design Parameters of Isolators

Isolation Bearings	**Parameter and unite**	**T(sec) =2.5 (Design Period)**		
		B(%) = 20 (Effective Damping)		
		D(mm)=200 (Design Displacement)		
		4 storey	**6 storey**	**8 storey**
HDRB	W(kN)	1098.5	1569	2039.5
	K_{eff} (kN/m)	694	991	1289
LRB	W(kN)	1098.5	1569	2039.5
	K_{eff} (kN/m)	694	991	1289
	K_1 (kN/m)	4760	6800	8840
	K_2 (kN/m)	476	680	884
	Q (kN)	43.6	62.3	81
FPB	W(kN)	1098.5	1569	2039.5
	K_{eff} (kN/m)	818.6	1169.2	1519.8
	K_1 (kN/m)	70840	101230	131580
	K_2 (kN/m)	708.4	1012.3	1315.8
	Q (kN)	22	32	47.6
	μ (friction coefficent)	0.02	0.02	0.02
	R (Radius of curvature, mm)	1550	1550	1550

1.2 Description of 2D Hospital Buildings

In general, the low to medium rise structures which have short periods and high accelerations are suitable for seismic isolation systems. For this purpose, reinforced concrete structures which have four, six and eight stories were chosen for simulations. The geometric configurations of the different number of stories of the 2D structures are shown in Fig.1. 300x600 mm beam and 300x900 mm column sizes were considered with 3 spans (5 m). The height of stories are three meters for all buildings. The material properties of the frame elements were defined C30 concrete grade and S420 rebar. Dead load and live load were taken as 5 kN/m^2 and 3.5 kN/m^2. The analyzed buildings are typical hospital structures in Turkey.

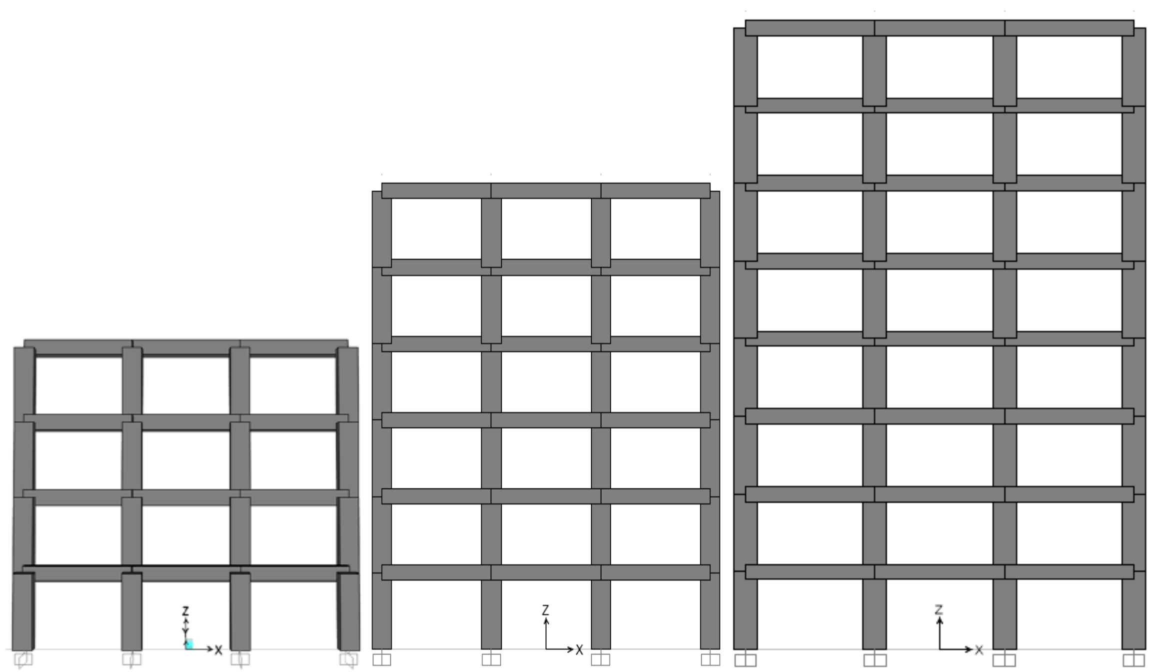


Fig. 1 – Fixed Buildings

1.3 Earthquake Data

Three different isolation models mentioned above were subjected to each of three different earthquake input motions.

1. The August 17, 1999 Kocaeli earthquake recorded at Gebze Tübitak Marmara Research Centre. Peak acceleration (NS), magnitude and earthquake depth are 0.27g, 7.5 and 16 km, respectively. Data is shown in Fig. 2.

2. The May 18, 1940 El Centro (EW) earthquake recorded. Peak acceleration, magnitude and earthquake depth are 0.21g, 6.9 and 16 km, respectively. Data is shown in Fig.3.

3. The February 27, 2010 Chile Angol (EW) earthquake recorded. Peak acceleration, magnitude and earthquake depth are 0.69g, 8.8 and 35 km, respectively. Data is shown in Fig. 4.

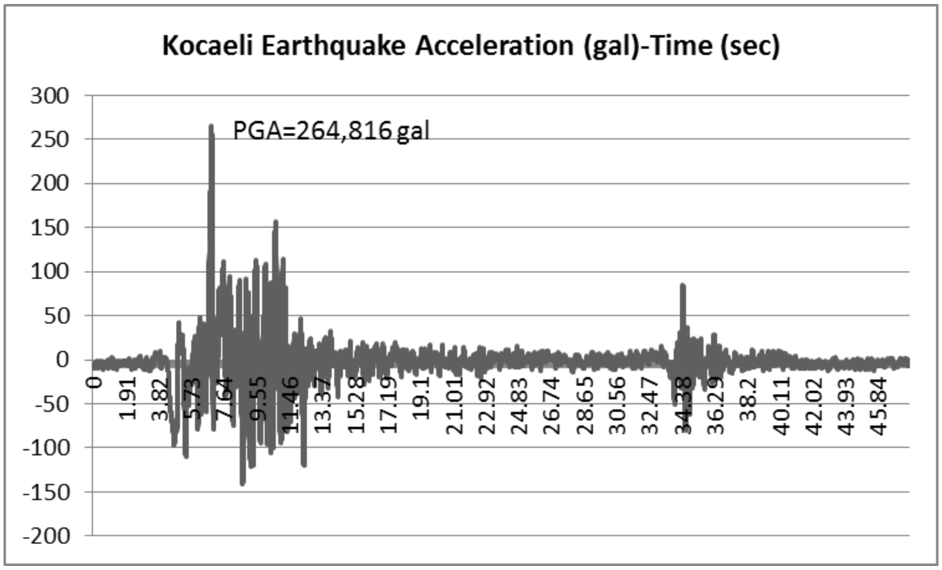


Fig. 2 – Kocaeli Earthquake Data

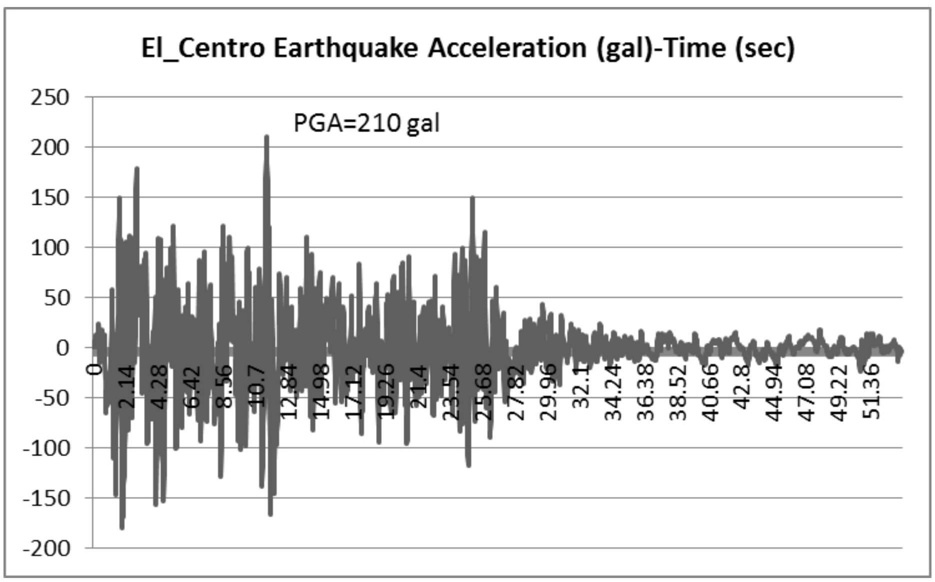


Fig. 3– El_Centro Earthquake Data

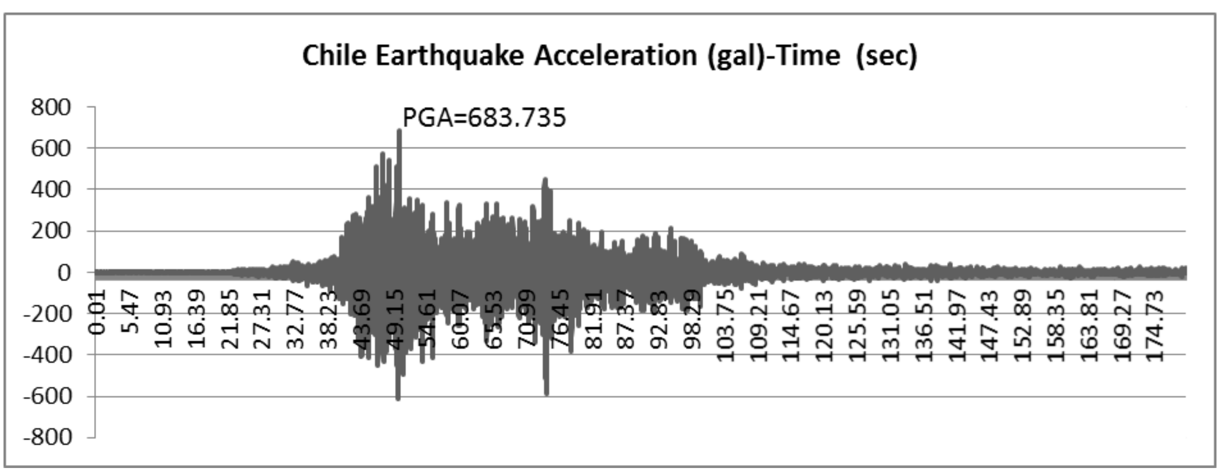


Fig. 4– Chile Earthquake Data

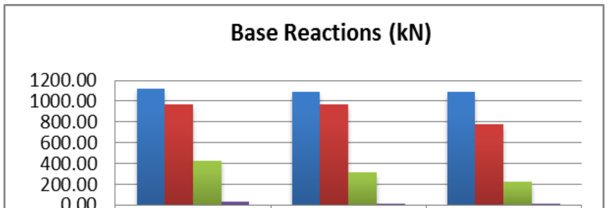
2. Results and Discussion

To compare fixed and isolated base buildings were modeled in the SAP 2000 software. Nonlinear time history analysis with three input earthquake data above were adopted for fixed and isolated buildings. The response of typical 2D four, six, eight stories structures were investigated for Chile earthquake data which have maximum values in terms of the relative displacement, the floor absolute accelerations and the base shears.

Displacement with respect to LRB, HDRB and FPB for different number of stories are represented by Fig. 5. It is seen that all structures behave rigid body motion. LRB isolator made maximum displacement. Four and six story structures, the story displacement of HDRB isolator was larger than in FPB isolator, although this was opposite in the eight story structures.

Fig. 5– Displacement of different stories

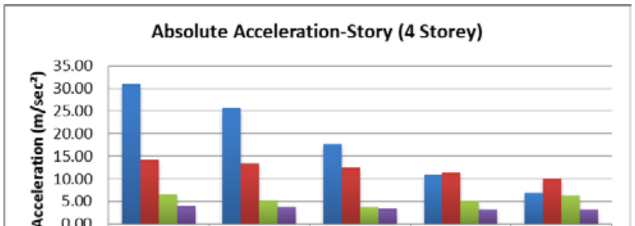
Base reaction for fixed base, LRB, HDRB and FPB isolators are represented and values are shown in Fig. 6. It is clear that FPB isolators are much more effective for decreasing base reaction forces for all different number of stories buildings. Also, HDRB and LRB isolators reduces the base shear forces respectively.



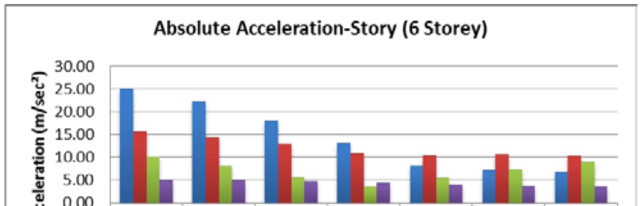
	8 Storey	6 Storey	4 Storey
Fixed	1124.79	1087.80	1088.77
LRB	972.19	970.51	776.35
HDRB	423.19	318.68	225.11
FPB	29.62	14.46	6.73

Fig. 6– Base reactions

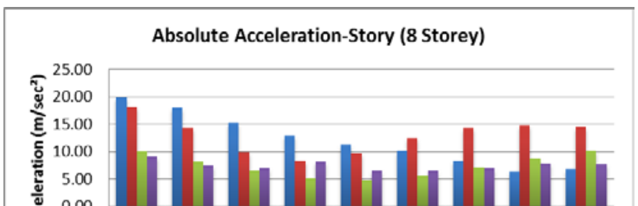
Acceleration with respect to different number of stories and isolators are represented and values are shown by Fig.7. Floor accelerations reduced significantly with isolation systems. Also, it is observed that FPB isolator is efficient for decreasing floor accelerations.



	4th	3rd	2nd	1st	Basement
Fixed	30.95	25.68	17.74	11.05	6.84
LRB	14.12	13.47	12.54	11.32	10.11
HDRB	6.48	5.13	3.67	5.06	6.25
FPB	3.87	3.67	3.37	3.23	3.21



	6th	5th	4th	3rd	2nd	1st	Basement
Fixed	25.11	22.34	18.02	13.09	8.10	7.17	6.84
LRB	15.80	14.50	12.86	10.89	10.59	10.65	10.30
HDRB	10.10	8.15	5.79	3.60	5.59	7.47	9.08
FPB	5.05	5.03	4.77	4.40	4.00	3.70	3.53

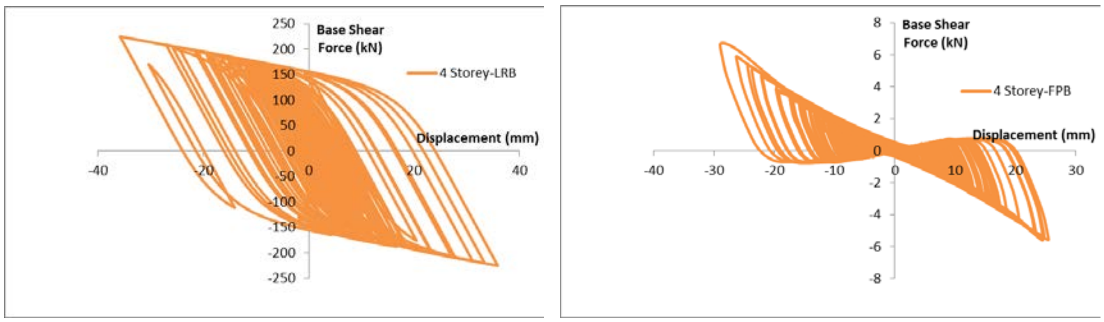


	8th	7th	6th	5th	4th	3rd	2nd	1st	Basement
Fixed	19.87	18.00	15.25	12.90	11.27	10.15	8.26	6.34	6.83
LRB	18.15	14.35	9.88	8.32	9.71	12.49	14.25	14.80	14.55
HDRB	9.94	8.10	6.49	5.06	4.74	5.60	7.08	8.73	10.13
FPB	9.05	7.38	6.95	8.11	6.54	6.43	6.97	7.83	7.75

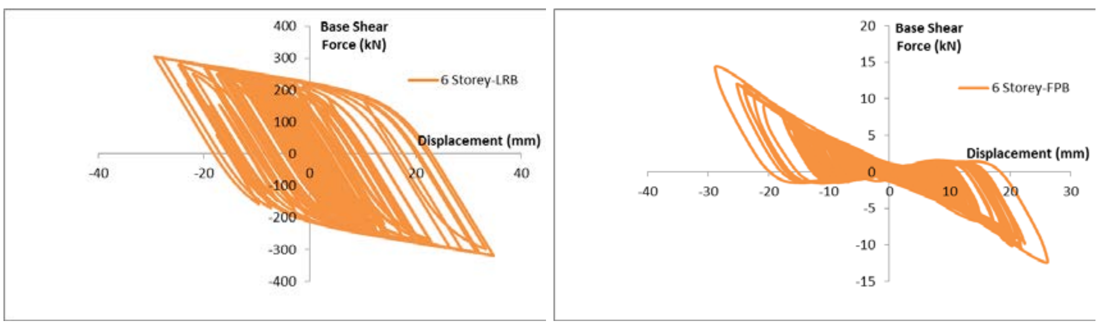
Fig. 7– Absolute Acceleration of Stories

Hysteretic response of base isolation systems are shown in Fig.8.

4 stories



6 stories



8 stories

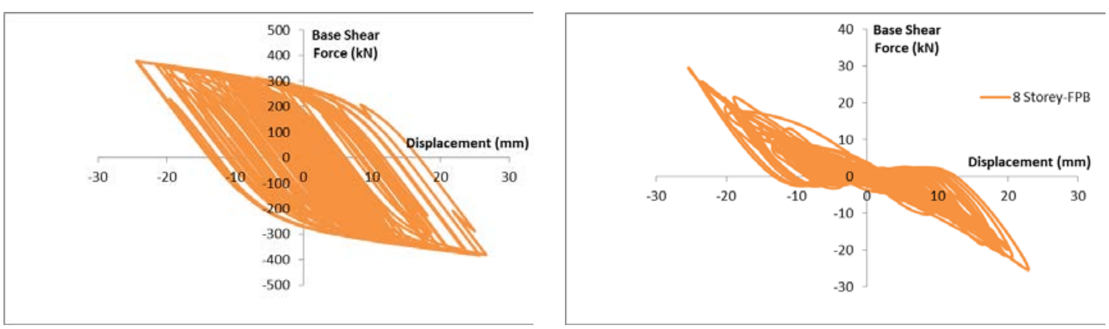


Fig. 8– Hysteretic response of base isolation systems

3. Conclusion

The type and structural characteristics of the building, using the given design requirements, must be considered while selecting the appropriate isolation systems. Non-linear systems like hysteretic or frictional behavior, are more effective in reducing large relative displacements and base shears, particularly under extreme seismic loads. In this study, the high base shears and floor accelerations were reduced by three types of isolation bearings. FPB isolation systems is more effective than other bearings. Within these results, FPB isolation, effectively decreases corresponding maximum response values of the fixed supported structure. HDRB isolation also reduces response of the earthquake, however initial rigidity is necessary to prevent displacements under other lateral loads. As well as, objective and available funds for a particular project also must be determined to decide which isolation system needed.

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