INVESTIGATION OF BASE-ISOLATOR TYPE SELECTION ON SEISMIC BEHAVIOR OF STRUCTURES INCLUDING STORY DRIFTS AND PLASTIC HINGE FORMATION

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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 effect of using two different types of seismic isolators in decreasing the base shear and story shears of structure has been investigated. Four structural models with 2, 5, 8 and 12 stories for three cases including fixed-base, lead-rubber isolator and friction pendulum isolator with different stiffness have been modeled. All models have been analyzed under earthquake characteristics of Manjil, Naghan, Tabas and Elcentro using a nonlinear finite element program. The results indicate that by using lead-rubber isolators, maximum displacements of stories in low-rise structures have been increased in comparison with fixed-base model. In contrast, in majority of cases, applying the FPS isolators doesn't guarantee the displacement requirement. Also by using isolators, number of cycles related to displacement response would be decreased especially in models with lower stories. In short base isolated structures, the decrease in plastic hinge formation percent of elements is much more than in fixed-base structures. With regards to the results that are mainly based on Iranian earthquakes characteristics, it could be concluded that seismic isolation is a useful method if being applied in short structures. Finally by comparing the hysteretic responses of structural models in three explained cases, it is revealed that the greater the design period of isolator, the higher level of energy dissipation by isolation system.

KEYWORDS: Isolator, Base Shear, Drift, Seismic, Plastic Hinge.

1. INTRODUCTION

Earthquakes cause inertia forces proportional to the product of the building mass and the ground accelerations. As the ground accelerations increases, the strength of the building must be increased to avoid structural damage. It is not practical to continue to increase the strength of the building indefinitely. In high seismic zones the accelerations causing forces in the building may exceed one or even two times the acceleration due to gravity, g. it is easy to visualize the strength needed for this level of load, which means that the building could be tipped on its side and held horizontal without damage. Base isolation is one of the most widely accepted techniques to protect structures and to mitigate the risk to life and property from strong earthquakes. Earthquakes will happen and are yet uncontrollable; so it should be tried to increase the capacity (Chopra, 2001, PEER, 2001 and Fukurawa et al., 2005).

Extensive experimental and numerical studies have been conducted to verify and enhance the design and analysis theories available for base-isolated structures. Kelly et al. (1980) conducted shaking table tests of a base-isolated building structure. Lee (1980) investigated the effects of the eccentricities in the superstructure and in the isolation system of a base-isolated single-story structure. Kelly and Pan (1983) determined the effects of the two-way eccentricity and damping ratio of the isolation system. Kelly et al. (1986) tested a base-isolated rigid block by lead-rubber bearings. The bearings were shaken up to the rollover displacement. Eisenberger and Rutenburg (1986) studied the effects of different ground motions on a one-way eccentric base-isolated building. Griffith et al. (1988) evaluated the effect of column uplift on the seismic response of a base-isolated building. Al-Hussaini et al. (1993) performed a series of tests on a base-isolated building with the friction pendulum system. Nagarajaiah et al. (1993) included parameters such as the superstructure flexibility, the uncoupled torsional to lateral frequency ratio, the eccentricities in the superstructure and isolation system, and the higher modes of vibration. Makris et al. (1996) investigated the efficiency of the isolation system type by considering a steel-frame base-isolated residential building located in Los Angeles, California. They found that the isolation system reduced the peak acceleration of the superstructure by approximately 45%. Hwang and Ku (1997) correlated the results of a rigid block isolated by high damping rubber bearings with those predicted by an analytical model. Hwang and Hsu (2000) investigated the response of isolated buildings under tri-axial ground motion and also Furukawa et al. (2005) studied the effectiveness of system identification of base-isolated structures on their seismic response.

In this paper the behavior of base-isolated structures with two different types of isolation systems (lead robber and friction-pendulum isolators) are compared with each other and also compared with fixed base structures considered as control model. First of all the characteristics of base isolators are generally investigated and then the numerical modeling of these isolation systems are developed. Finally the results including the base shear story displacements and plastic hinges are compared based on isolator type, different models with different story levels, different design periods and also the earthquake motions.

2. NONLINEAR NUMERICAL MODELING

Nonlinear analytical modeling techniques were used for dynamic analysis of structural models. The structural models were analyzed under 3 dominant earthquake time histories of Iran including Manjil, Tabas and Naghan earthquakes and also under the international earthquake of Elcentro. All the mentioned time histories were normalized due to peak acceleration of 0.56g. The characteristics of the earthquakes are available in Table 1.

2.1. Characteristics of Investigated Models

Structures investigated include 2, 5, 8 and 12 story steel models in which the earthquake resistant systems are bending frames. These structures have four 6-meter bays and floors with 3.6 meters height. Each of the structures by considering two types of isolators and three different design periods (2, 2.5 and 3 sec. (s)) are analyzed under Manjil, Tabas and Naghan earthquakes and also the international earthquake of Elcentro. Consequently 28 structural models have been investigated that is equal to 112 nonlinear analyzes performed.

2.2. Identifying the Isolators Design Characteristics

The isolators are modeled by a bilinear model based on the three parameters: K_1, K_2, and Q (Naeim and Kelly 1999) as shown in figure 1. Isolators will have high initial stiffness, K_1, and after yielding they will have lower stiffness, K_2. The initial stiffness K_1 is estimated from a hysteresis loop from lead-rubber bearing tests or as a multiple of K_2 for lead–plug bearings. The characteristic strength, Q, is estimated from the hysteresis loops for lead-rubber isolators. For lead–plug isolators, Q is given by the yield stress in the lead and the area of the lead. The hysteretic damping of this bearing is due to the plastic deformation of the lead. A procedure to determine the post-yield stiffness, K_2, is shown below (Pradeep Kumar & Paul 2007).

Table 1.Characteristics of earthquake 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
Tabas	1978	0.923g	25 sec
Naghan	1977	0.723g	5 sec

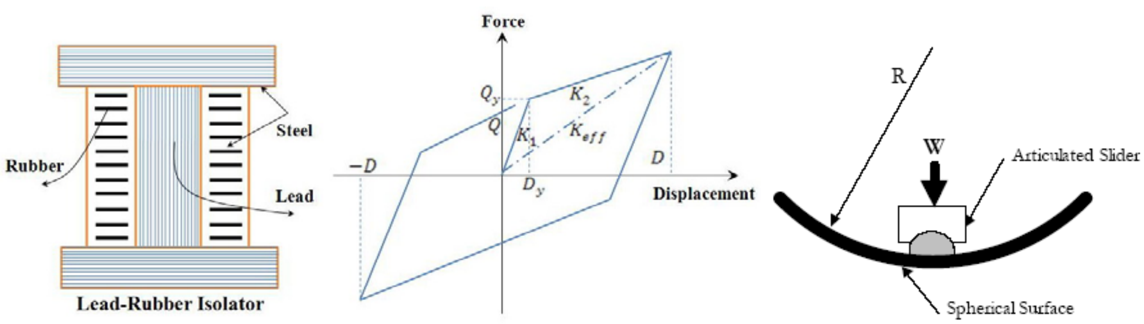
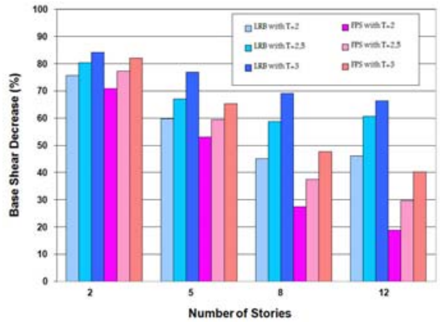


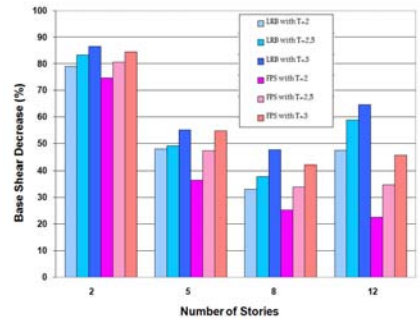
Figure 1 Bilinear modeling of isolated bearing

3. COMPARISON OF BASE SHEARES

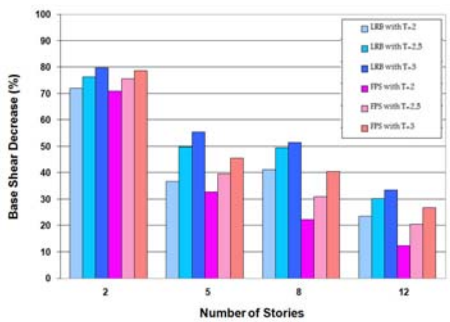
Figure 2 indicates the decrease in the base shear of structural models versus different models for both lead rubber and FPS isolators with different design periods under mentioned earthquake generally as it can be seen from the bar charts, it is obvious that by increasing the number of story in structural models the decrease percentage of base shear would be reduced; As a common concept this result is due to the rigid behavior of superstructure incase of increasing the stiffness of structures that would lead to better performance of isolators. Also by design period elongation, the effective stiffness of isolators decrease and conversely the decrease in base shear will be increased.



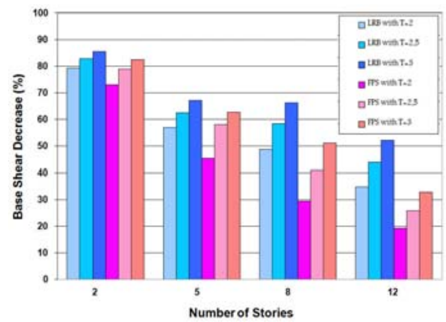
(a) Elcentro Earthquake



(b) Manjil Earthquake

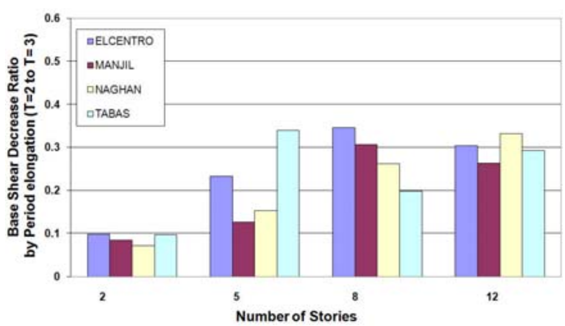


(c) Tabas Earthquake

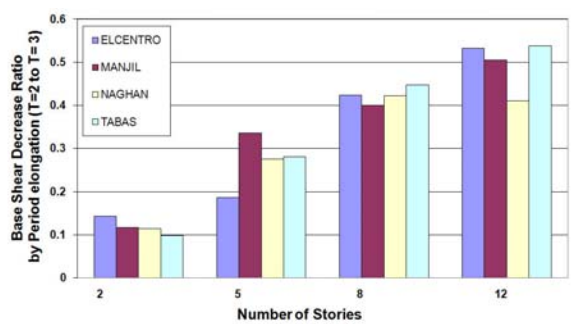


(d) Naghan Earthquake

Figure 2 Base shear decrease



(a) Friction Pendulum Isolator

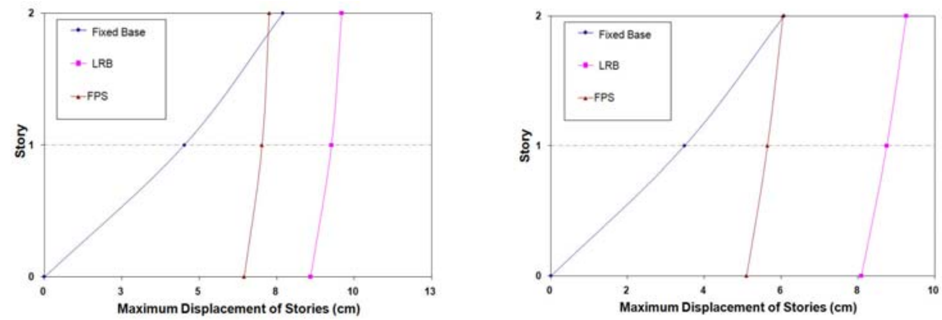


(b) Lead Rubber Isolator

Figure 3 Ratio of base shear decrease by period elongation from T=2 to T=3 sec.(s).

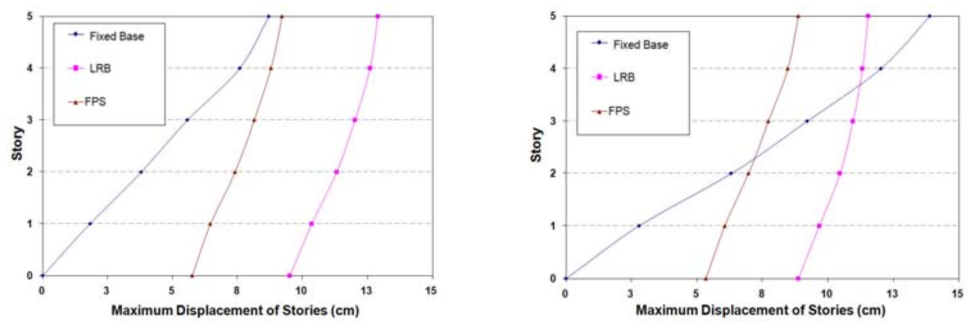
4. COMPARIOSON OF LATERAL MAXIMUM DISPLACEMENTS WITH FIXED BASE MODELS

In this section in order to investigate the precise behavior of isolators, the maximum displacement of story levels under mentioned earthquakes are studied; but only the results of maximum displacement for lead rubber and FPS isolators with design period of T=2.5 sec. are considered. In figures 4 to 7 the maximum displacement under Elcentro and Tabas earthquake versus the story levels are shown. As it can be seen from the figures the variation in maximum displacement of stories in base isolated structures compared with fixed base models is very low but by increasing the number of stories this variation will be somehow considerable, in which in 12-story structure the variation of maximum displacements in base isolated structures is very close to fixed base models. This significant characteristic of base isolation systems would affect the superstructure to have rigid movement and as a result the relative displacement of structural element will decrease and consequently the internal forces of beams and columns will be reduced.



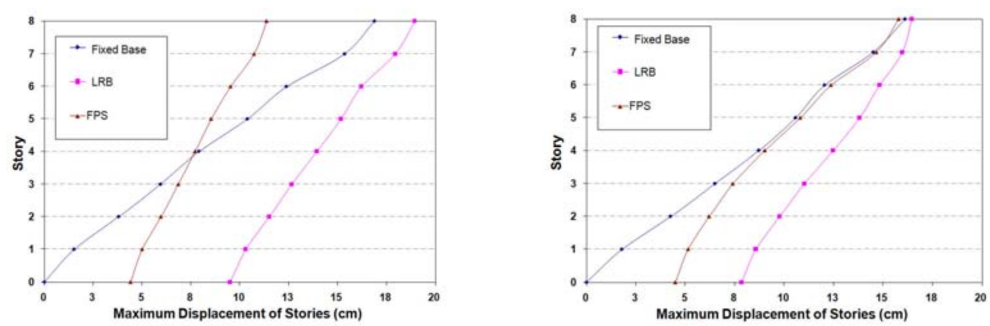
(a) Elcentro Earthquake (b) Tabas Earthquake

Figure 4 Maximum story-displacements of 2-story models.



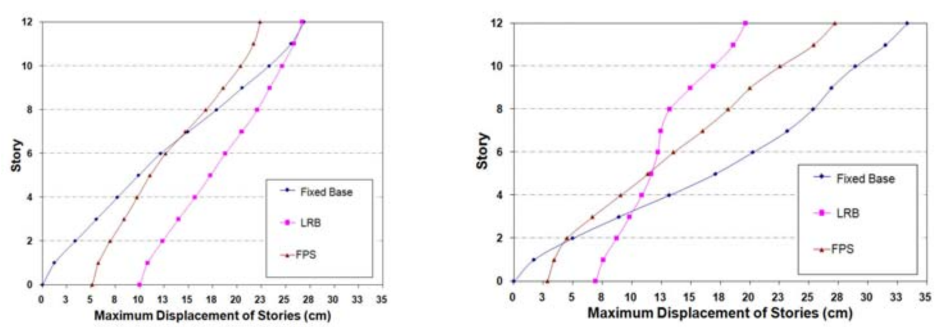
(a) Elcentro Earthquake (b) Tabas Earthquake

Figure 5 Maximum story-displacements of 5-story models.



(a) Elcentro Earthquake (b) Tabas Earthquake

Figure 6 Maximum story-displacements of 8-story models.



(a) Elcentro Earthquake (b) Tabas Earthquake

Figure 7 Maximum story-displacements of 12-story models.

5. PLASTIC HINGE FORMATION

One of the most important aspects in vulnerability of structures under earthquake loads is diagnosing the weak points in structural elements and also their positions. Determining the formation of plastic hinges will aware the designer about critical point of structure and due to that the best way of strengthening and retrofitting could be identified in this section a comparison between plastic hinges generated in fixed base and base isolated structures under mentioned earthquake has been investigated. In figure 8 deformation of plastic hinges for fixed base structures under different earthquake is shown as it can be seen from the figure, in 5 and 8-story structures under Manjil and Naghan earthquakes no hinge is generated. In figure 9 the percentage of plastic hinge formation in structural elements for 12-story model with two isolators (LRB and FPS) and different design periods is presented. As it can be seen from the figures base isolation will decrease the percentage of plastic hinge formations considerably.

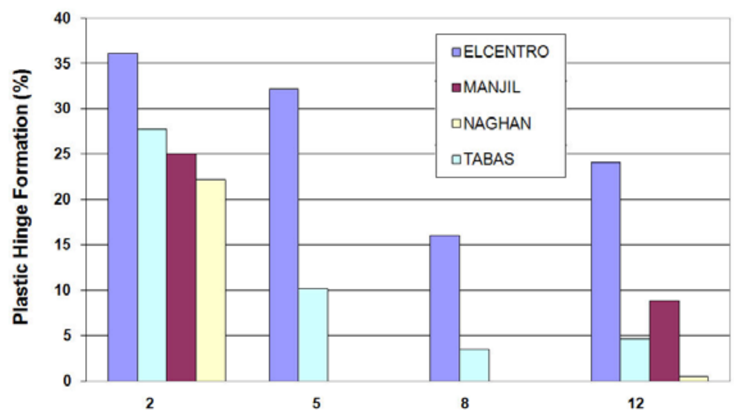


Figure 8 Plastic hinge amount generated in fixed base structures.

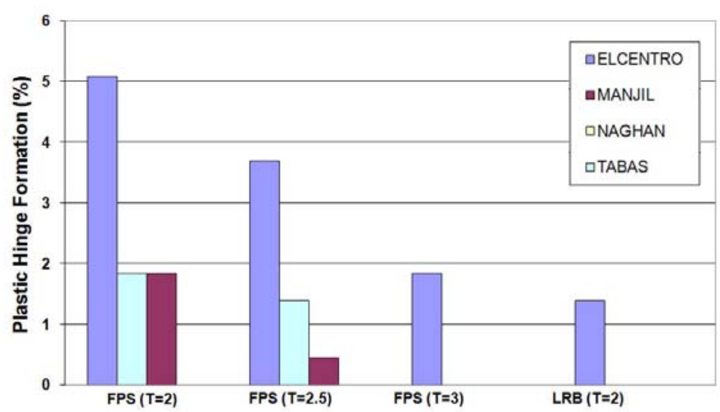
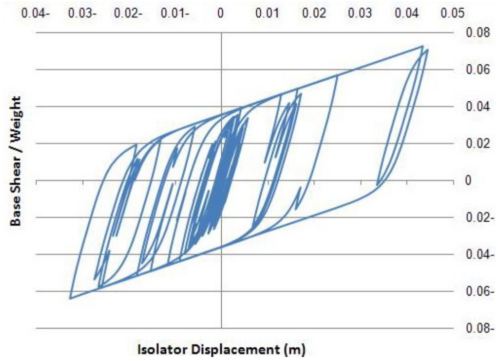


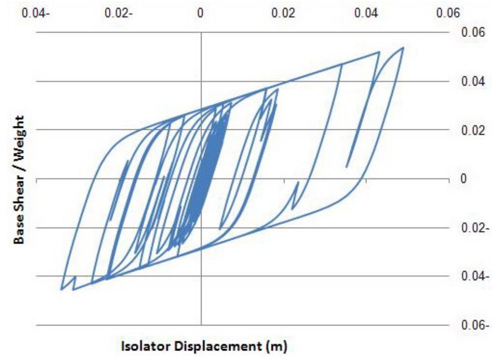
Figure 9 Plastic hinge amount generated in base isolated 12-story models.

6. HYSTERETIC RESPONSE OF BASE ISOLATED MODEL

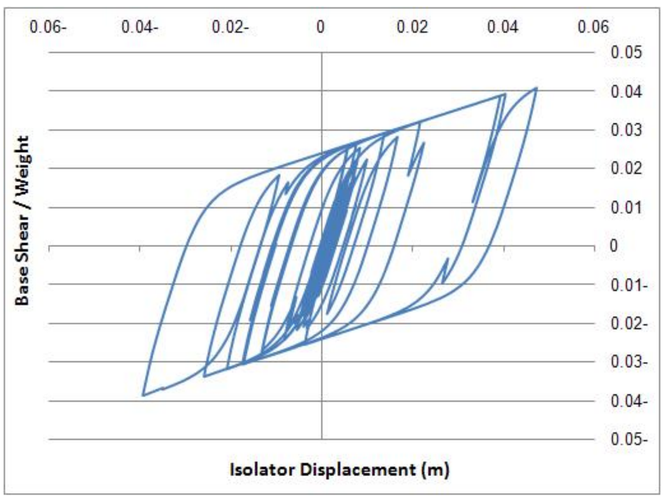
In figure 10 the hysteretic responses of 8-story structures with different design periods under Elcentro earthquake is shown. By comparing the hysteretic responses of structural models in three explained cases, it is revealed that the greater the design period of isolator, the higher level of energy dissipation by isolation system.



(a) Isolator period of T=2 sec



(b) Isolator period of T=2.5 sec



(c) Isolator period of T=3 sec

Figure 10 Hysteretic Responses under Elcentro earthquake (8-story model)

7. CONCLUSION

From the discussion of results obtained numerical modeling, the following conclusions can be drawn:

- The decrease in base shear and also the story shear with design elongation of isolators because of reduction in stiffness of isolators will be increased. But this increase in design period will result in some restrictions. One of the most important of these limitations is increasing in displacement of structures. In fact with period elongation, the displacement in isolator level because of rigid displacement of structure will increase.
- In tall buildings, the period elongation would effectively decrease the base shear of structure. So in designing these structures a considerable in base shear can be achieved by decreasing the effective of isolator.
- Lead rubber isolators generally increase the maximum displacement of structures in low rise buildings compared with fixed base structures but in high rise buildings the difference is negligible.
- Generally speaking, in FPS isolators in majority of cases their maximum displacement is not greater than fixed base structures that indicate that these isolators are effective even in decreasing the maximum displacements.
- By comparing the hysteretic responses of structural models in three explained cases, it is revealed that the greater the design period of isolator, the higher level of energy dissipation by isolation system.

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