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Influence of the Isolator Characteristics on the Response of the Isolated Buildings in the Near-Fault Earthquakes

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Abstract

Seismic base isolation are devices that used to limit the human and material damage caused by an earthquake. This devices diffuse the energy induced at the time of the earthquake before being transferred to the structure.The base isolated structures when subjected to the near-fault eathquakes which contain long-period velocity pulses that may coincide with the period of base isolated structures resulting in excessive deformation and rupture of isolators. Parameters of base isolation such as the yield strength and post yield stiffness ratio have significent effect on the displacement of isolation system. To study this effect, influence of these parameters on the dynamic response of the isolated structures in term of displacment, acceleration, base shear and absorbed energy has been studied. The results show that the increase in the bearing yield strength can reduce the bearing displacment signficantly without much alterning to the superstructure accelerations. Also the optimum yield strength and post yield stiffness ratio of the LRB is found to be in range of 0.8% - 1% of the total weight of the building and 0.08 – 0.12 of the ratio of plastic stiffness to elastic stiffness of base isolation respectively under near fault motions.

Keywords: Lead rubber bearing, Yield strength, bearing displacement, Dynamic response

1. Introduction

Result of researches have shown that the base isolation structures did not respond suitable to near filed earthquakes. The importance of the near-fault (NF) earthquakes characteristic has been studied deeply during the last couple of decades. Large amplitude, long period and existence of long period pulse in velocity records are the main characteristics of NF earthquakes [1-2].

Seismic isolation, *which have been developed and used recently, decouples a structure or part of it from the damaging effects of ground accelerations. This devices shift the fundamental frequency of the structure away from the domain frequencies of seismic excitations and fundamental frequency of the fixed structure [3-4]. In addition, it's also provides an energy dissipation mechanism at the level of isolation, reducing the relatively large relative displacements between the superstructure and the supporting ground.

In recent years a series of new studies have been carried out on base isolated buildings under NF. A research was carried out by Jangid-R.S. in [5-6] seismic response of the multi-story buildings isolated by the LRB is investigated under NF motion. It was shown that the LRB with appropriate properties is quiet effective for seismic isolation of structures under NF motions. Also Chan. Win, A. in [7] shows that the story acceleration are reduced significantly in the base isolated building compared to the original building. Nevertheless, observation of behavior of base isolation shows significant increase in displacement of during near filed earthquakes [6].

Some studied have been conducted to reduce the displacement of isolation system in near-near filed by increasing the damping of structure (see [6]) and limited study have been conducted to reduce the displacement by changing other parameters of base isolation. In this study, in order to reduce the top structure displacement in LRB base isolation system, a parametric study have been conducted to evaluate the effect of different values of behaviour parameters such as yield strength and post yield stiffness ratio on displacement, acceleration, base shear and absorbed energy of LRB system.

2. Behaviour of the LRB base isolation

The LRB base isolation is composed of alternate layers of rubber and steel related the ones to the others around a pure lead core inserted into the center of these layers of steel and rubber. The lead core controls the lateral displacements of the structure and absorbs the seismic energy. The mechanical behaviour of the lead-rubber bearing can be approximated with a bilinear stiffness model shown in Figure1 [8]. The composition of this model is showed in Figure 2[9]. In the figure, the simplified linearized force versus displacement relationship for each of the components of the LRB is

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plotted. Figure 2-(a) represents the elastic stiffness of the rubber. This means that applied force is below the yield point of rubber. The simplified elastic-plastic nature of the lead plug is illustrated in Figure 2-(b), where it is assumed that lead exhibits perfectly plastic behaviour after the applied force has exceeded the yield strength of the lead plug. Finally, the combined stiffness of the lead plug and rubber bearing are shown in Figure 2-(c). It is evident that the elastic stiffness of the composite system is equal to the combined stiffness of the lead and rubber under low lateral loads, while the post-yield stiffness of the system is equal to only the stiffness of the rubber.

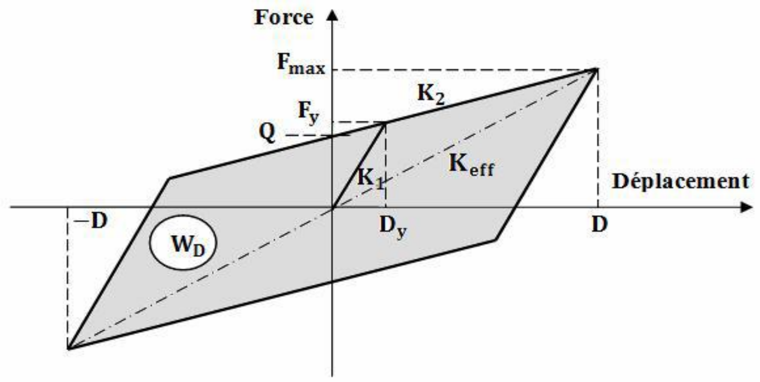


Figure1: Bilinear force-displacement of LRB [8].

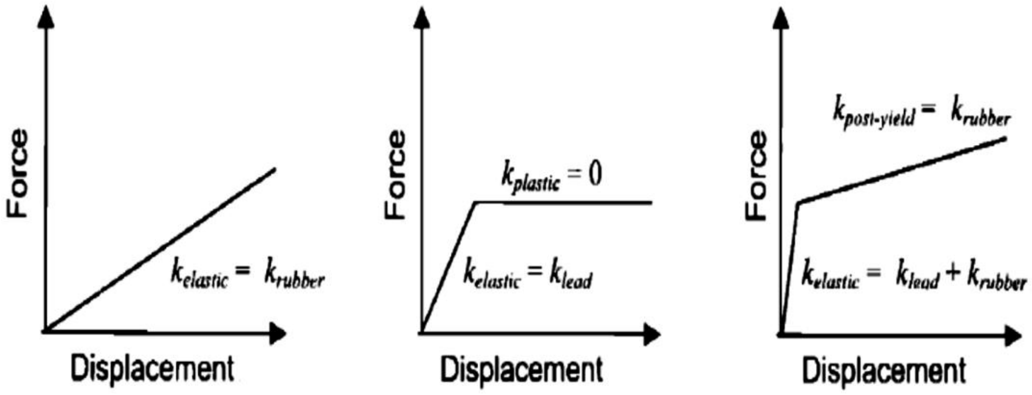


Figure2: Mechanical behaviour of LRB.

The bilinear model of LRB can be evaluated using following relations [4]:

$$D_D = (g/4\pi^2)(C_v T_D / T_D)^2,\ C_v = ZN_v \quad (1)$$

$$K_{eff} = (W_{DL+LL}/g)(2\pi/T_D)^2 = K_2 + Q/D \quad (2)$$

$$W_D = 2\pi k_{eff} . D_D{}^2 . \beta_{eff} = 4Q(D_D - D_y) \quad (3)$$

$$Q_d \cong W_D / 4D_D = F_y - K_2 D_y \quad (4)$$

$$K_1 = F_y / D_y \quad (5)$$

$$K_2 = (F_{\max} - F_y)/(D_D - D_y) \quad (6)$$

3. Study methodology

The main characteristic of LRB base isolation behavior is defined by yield strength (F_y) and post yield stiffness ratio (K_2/K_1) which controlled by the area and yield stress of lead core of base isolation controlled the deformation of the isolation bearing and consequently displacement and acceleration of superstructure. Selection of proper values for this parameters plays important rule in seismic design of base isolation buildings. To illustrate the effect of the yield strength and post yield stiffness ratio on dynamic response of structure in near-filed earthquake, a parametric analysis was conducted on 7 story RC isolated structure designed based on UBC-97 for high seismic zone. The range of variation of yield strength was selected from 0.3% to 1.1% of total weight ($F_0 = \frac{F_y}{W}$) of the building and the range of post yield stiffness ratio was selected from 0.06 to 0.16. The behavior of designed structure with different parameters was evaluated under several near-filed ground motions. Based on the result of analysis, the optimum range of study parameters were selected.

4. Description of the isolated structure and the seismic ground motion

The structure used in the parametric study is an isolated reinforced concrete building with a rectangle plan 20×20 m^2 including four 5 m spans in the longitudinal and transverse direction and height of a floors is of 3 m. The elevation view and floor plan of studied building illustrated in figure 3and 4.

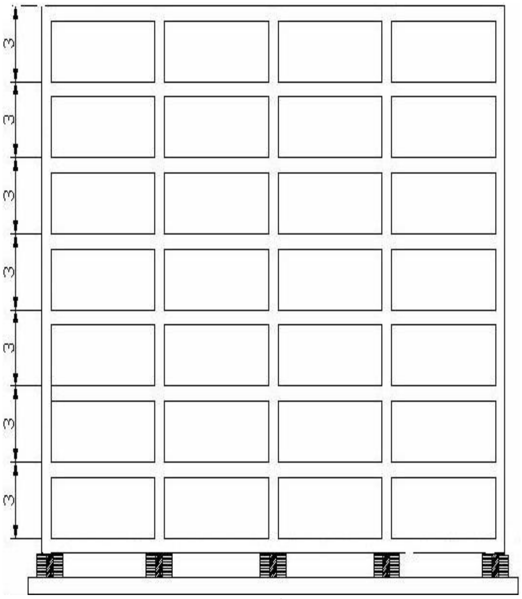


Figure 3: elevation view of selected structure

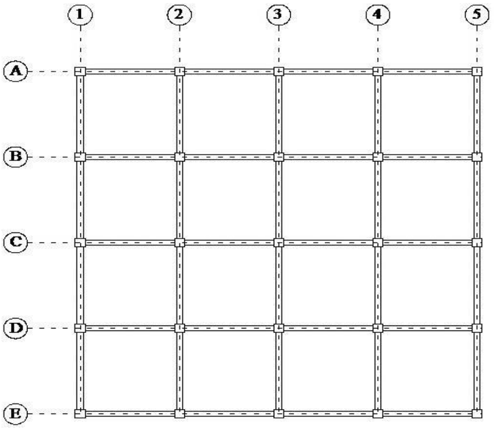


Figure 4: Plan of selected structure

The studied building is located in a high-seismic region, zone 4, and assigned a seismic zone factor Z=0.4 according to table 16-1 of UBC97. The closest distance to a known fault that is capable of producing large magnitude events and that has high rate of seismic activity (Class A seismic source according to Table 16-U of UBC97) is assumed to be 5 km [10]. The seismic coefficient of buildings is calculated as: $C_v = 0.4 \times 1.6 = 0.64$.

For design of LRB, the target period of $T_D = 2.5 \sec$ is selected. The detail calculation of LRB properties are as follows. The summary of results are given in table 1.

Table1: Dimension of LRB at design target period, $T_D = 2.5 \sec$

Name	h(cm)	h(cm)	N(Nos)	t(cm)	d_p(cm)	t_s(cm)	N_s(Nos)	T_{tp}(cm)
LRB	55	35	20	1	6	0.3	19	2.5

To conduct the parametric study, nonlinear dynamic analysis has been perform using six near fault ground motion with pulse. The selected records are:

1. The component of EI Centro of the earthquake of Imperial Valley (1979) with PGA 0.41 g.
2. The component of 77 Rinaldi of the earthquake of Northridge (1994) with PGA 0.82 g.
3. The component of TCU068 of the earthquake of Chi-Chi (1999) with PGA 0.56 g.
4. The component of 24Lucerne of the earthquake of Landerz (1992) with PGA 0.72 g.
5. The component of 16Lgpc of the earthquake of Loma Prieta (1989) with PGA 0.96 g.
6. The component of 9101Tabas of the earthquake of Tabas (1978) with PGA 0.83 g.

The velocity records of these ground motions are represented in figures 5.

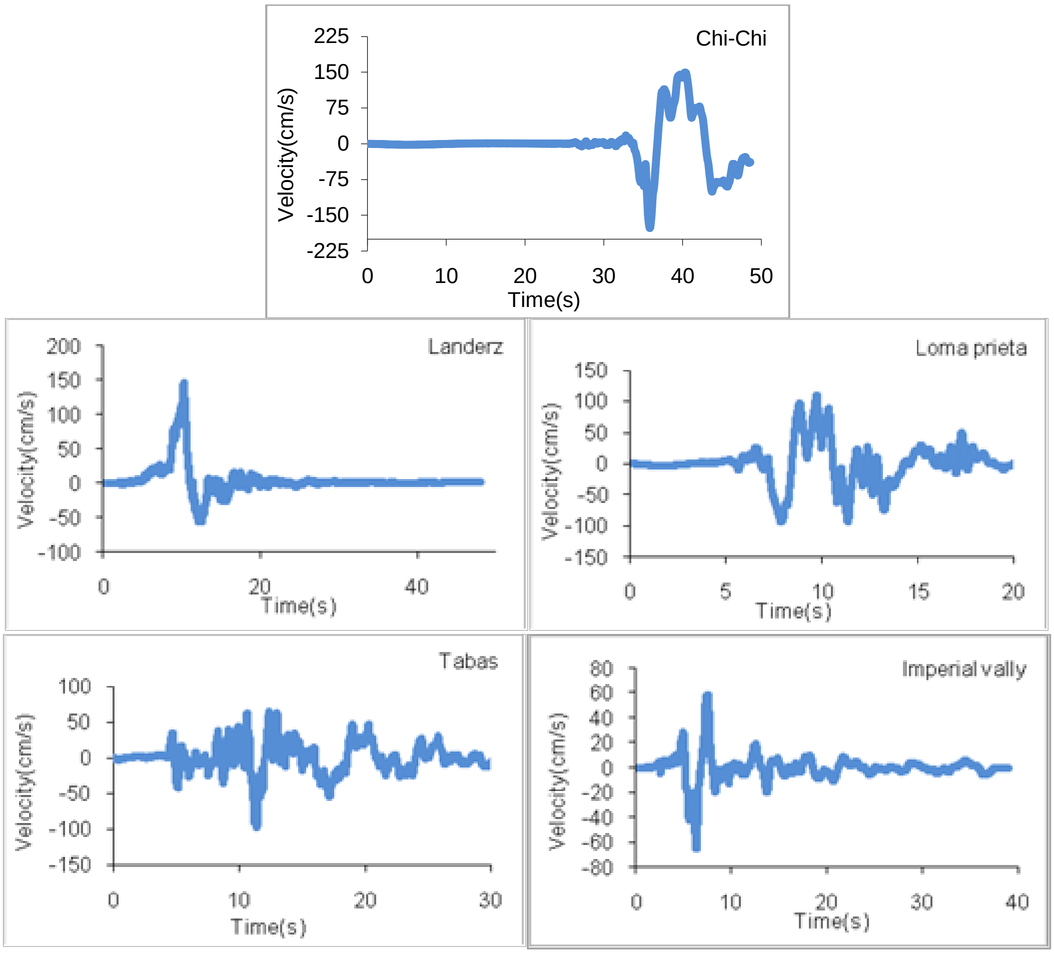


Figure 5: Velocity records of selected earthquakes.

5. Results and discussions

In this section, the effect of different studied parameters on displacement, acceleration, base shear and absorbed energy of selected building are studied

5.1 Displacements

In figure 6 and 7, the displacement of top of bearing and top of the structure are given for different percentage of yield strength and post yield stiffness respectively. A quick look at the result of analysis have shown that displacement of top of bearing in most cases are significantly higher than the expected value by design which is D_d=0.295 m, calculated in previous section. The higher displacement cause damage in the bearing in the near–filed earthquakes.

To reduce this gap, the parametric study was conducted. The result shows that under all analyzed records, the displacements of the superstructure and top of the isolation system decreased with the increase in the yield strength of lead and post yield stiffness ratio.

The optimum range of values of yield strength and post yield stiffness ratio that minimizing the story displacement in the structure can be obtained from figures are in the range of 0.8% - 1% of the total weight of the building for yield strength and 0.08 – 0.12 for the post yield stiffness.

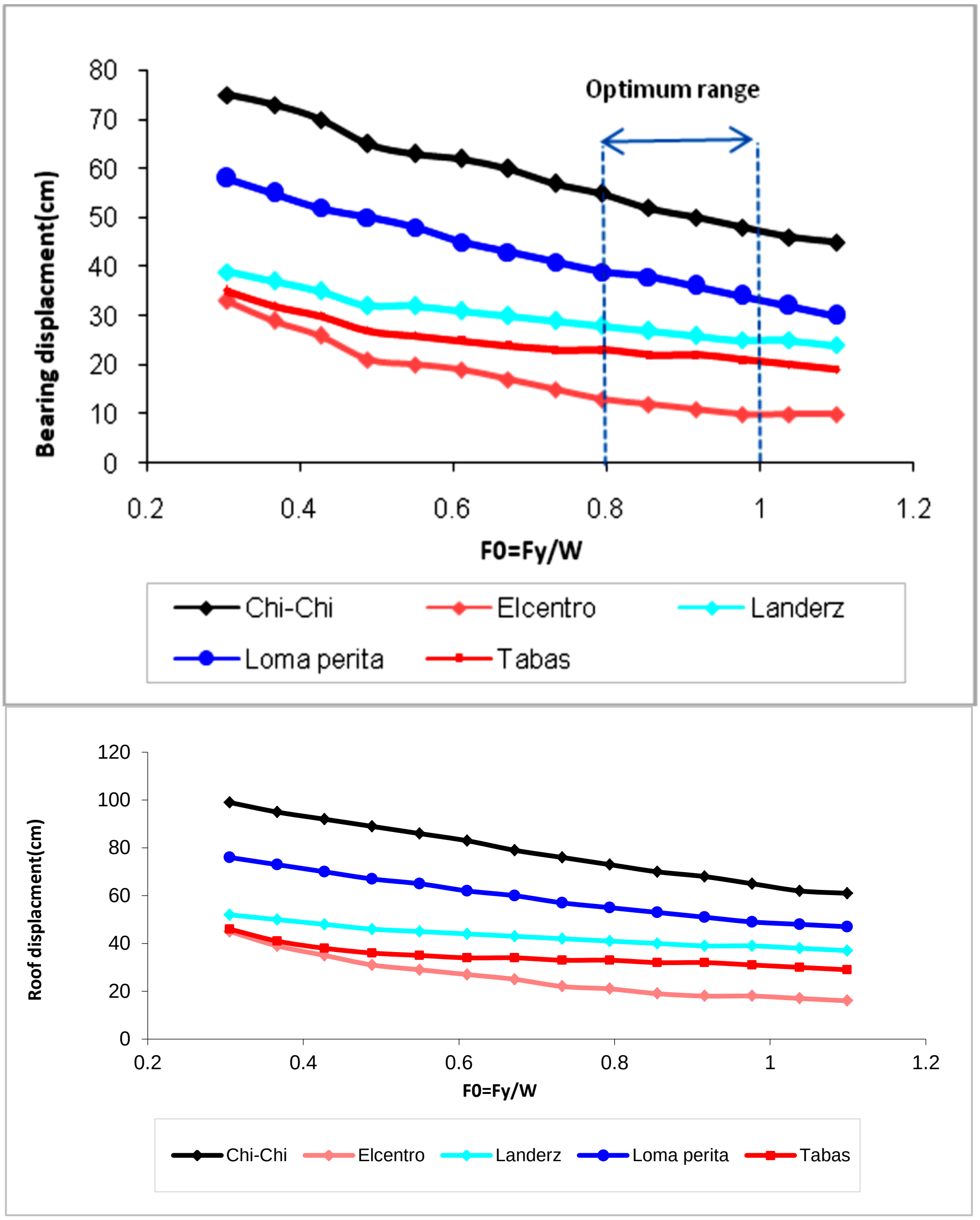


Figure 6: Maximum displacement of the top of base isolation and roof with the different percentage of yield strength

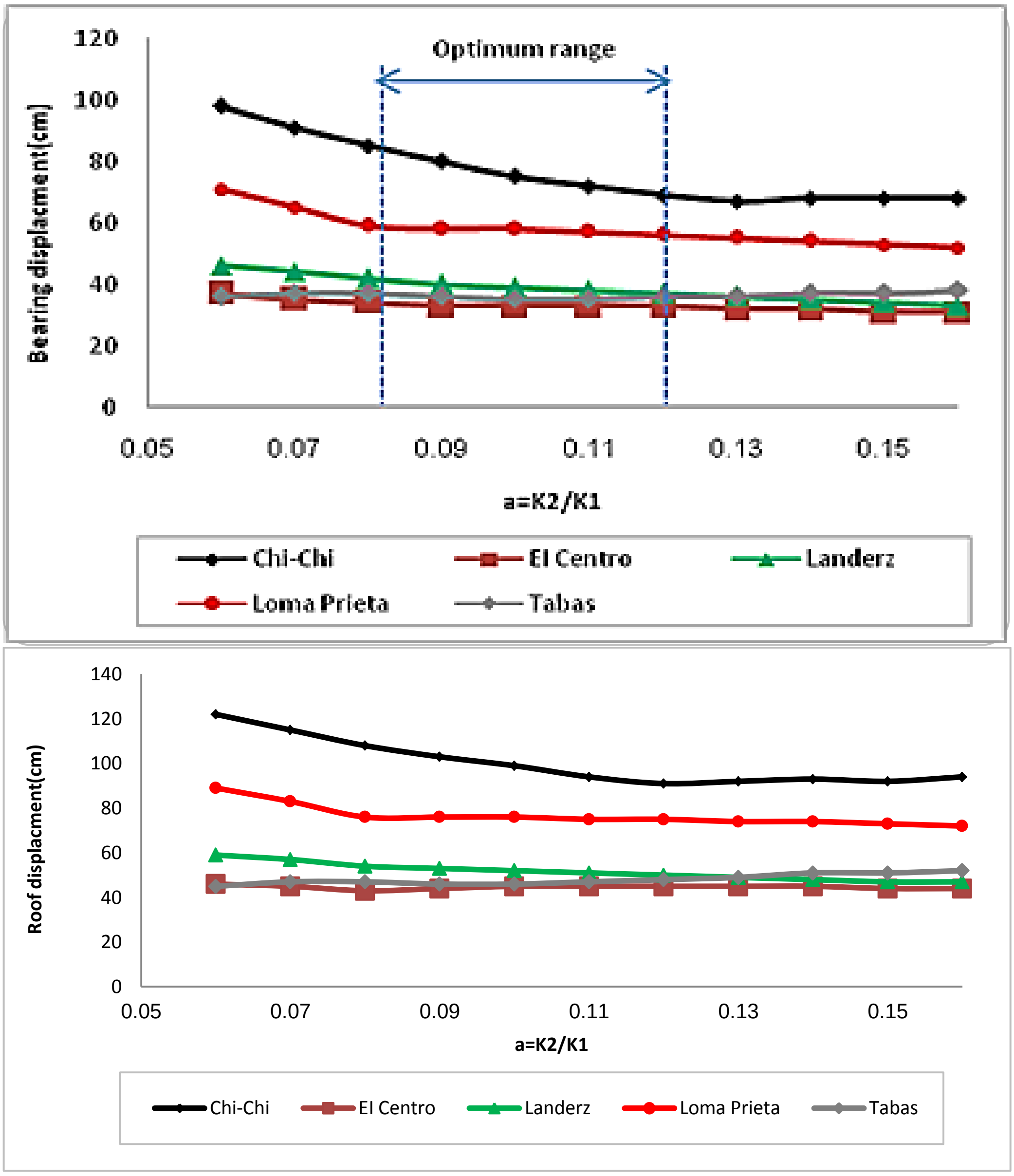


Figure 7: Maximum displacement of top of base isolation and roof with the different ratio of post yield stiffness

5.2 Acceleration

The maximum roof acceleration of studied structure under different percentage of yield strength and post yield stiffness are shown in Figure 8 and 9. It can be seen that the increase in the yield strength and post yield stiffness ratio of the LRB increases the roof acceleration under near-fault motions. From Figure 8, it can be observed that, the yield strength did not have much effect on the top floor acceleration. Take advantage of this fact, it can be observed that choosing the optimum value as presented in Figure 6 may not have significant increase in the top roof acceleration of structure. Therefore the selected optimum value may acceptable in this case. Similar situation also partially existed in the case of ratio of post yield stiffness given in Figure 9.

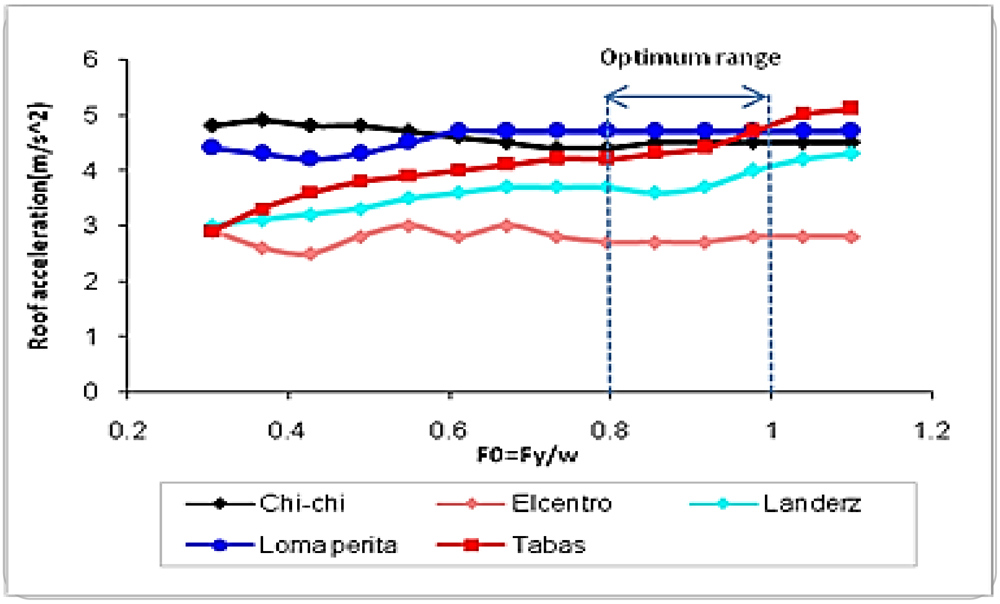


Figure 8: Maximum accelerations of 7th level with the different percentage of yield strength.

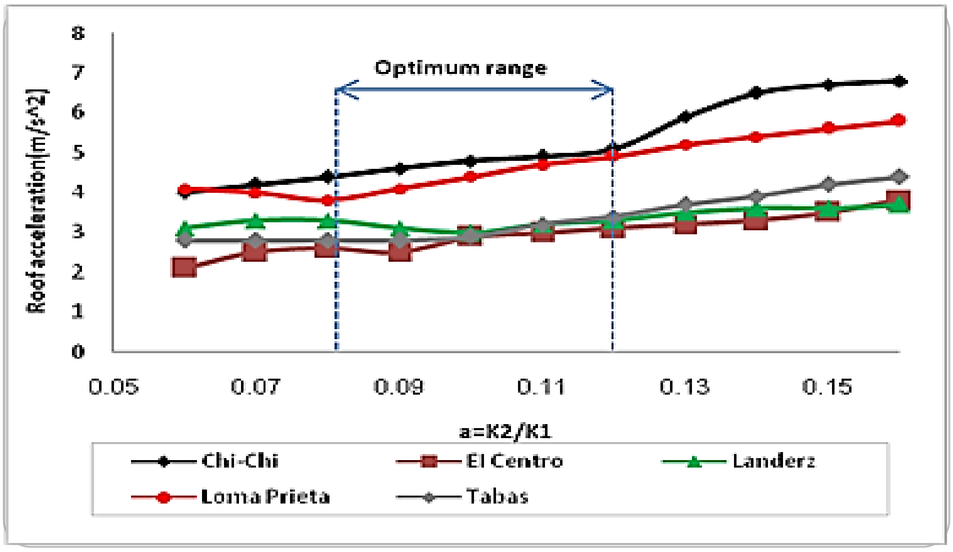


Figure 9: Maximum accelerations of 7th level with the different ratio of post yield stiffness.

5.3 Base shear

Figure 10 and 11 illustrate the variation of the base shear of isolated building against the percentage of yield strength and post yield stiffness ratio under near-fault motions respectively. The results shows that the base shear increase by increasing of both parameters. This demonstrate increase in design force of structure by increase of yield strength and post yield stiffness ratio.

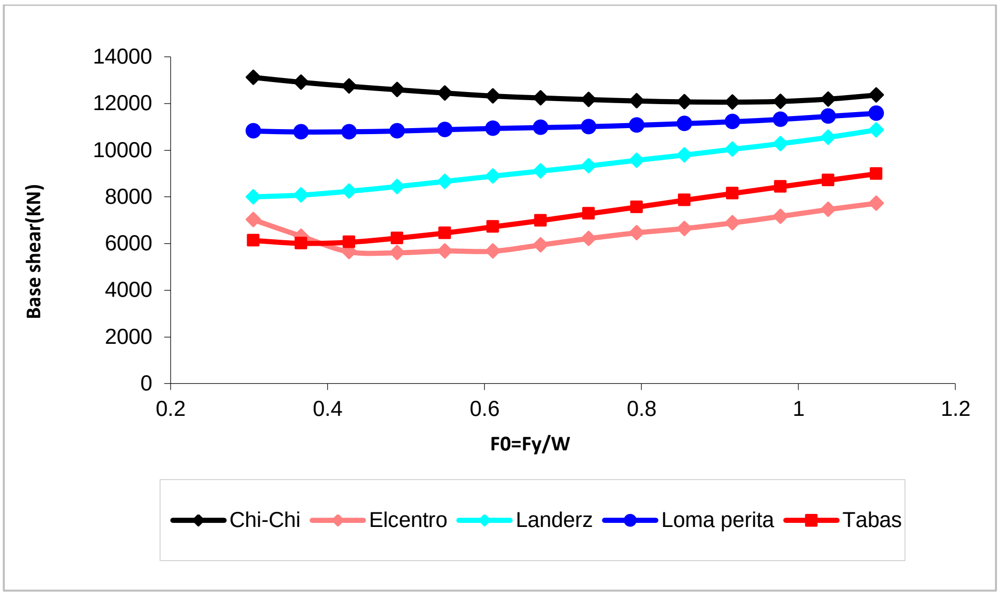


Figure10: Maximum base shear of isolated building with the different percentage of yield strength of lead.

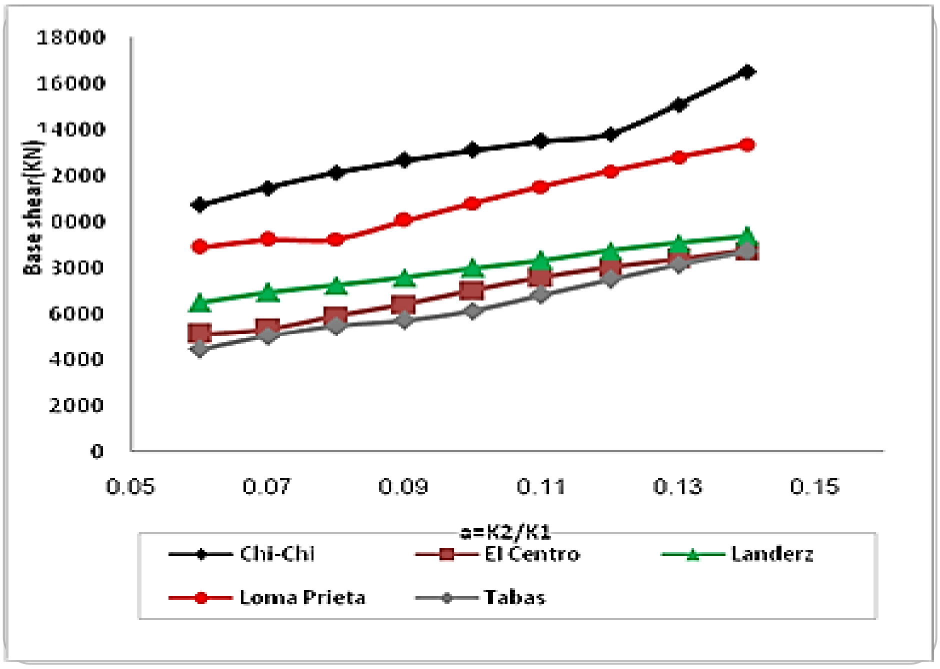
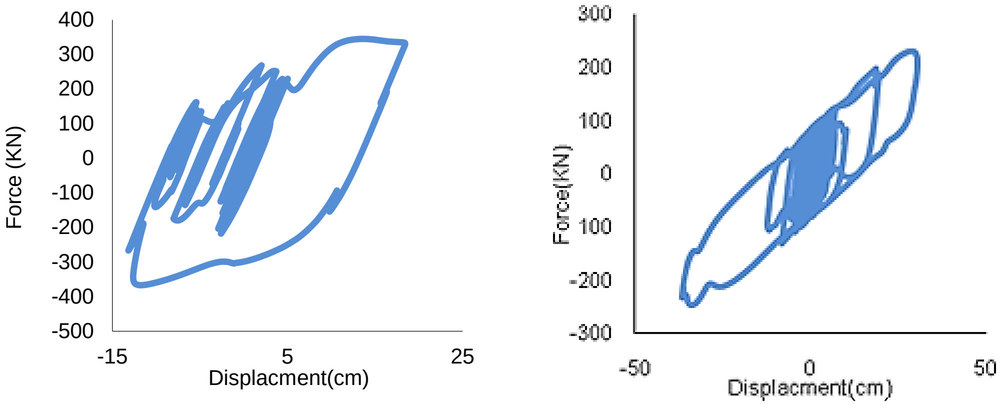


Figure11: Maximum base shear of isolated building with the different ratio of post yield stiffness.

5.4 Absorbed energy

To illustrate the effect of the yield strength of the seismic isolation system on the dissipation of energy, a comparison was made between the force-deformations diagrams of one of the central seismic isolation for two marginal yield strength percentage of 0.3%and 1.1% under Tabas and Landers earthquakes. The results of are shown in Figures12 and 13.

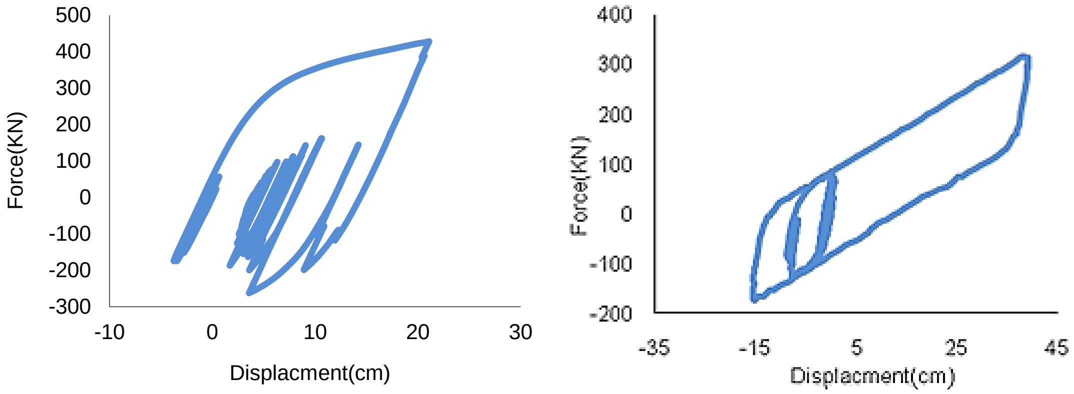
The results have shown that area of hysteretic loops are increased by increasing the yield strength. This demonstrate that increases of the yield strength of LRB increases the energy absorbed by the seismic isolation system.



12-a) Yield strength of 1.1%

12-b) Yield strength of 0.3%

Figure 12: Comparison of the diagrams force-displacements of a central seismic isolation for two value of yield strength percentage of 0.3and 1.1subjected to the component of Tabas earthquake.



13-a) Yield strength of 1.1%

13-b)Yield strength of 0.3%

Figure 13: Comparison of the diagrams force-displacements of a central seismic isolation for two value of yield strength percentage of 0.3and 1.1subjected to the component of Landerz earthquake.

6. Conclusions

In this study, to reduce the displacement of bearing system in near filed earthquakes, the effect of different values of ratio of yield strength of LRB to total weight of structure and ratio of post yield stiffness to initial stiffness on displacement, acceleration, base shear and absorbed energy of a 7 story concrete building was studied in the near filed of earthquake through non-linear dynamic analysis.

The results have shown that by increasing the yield strength and post yield stiffness ratio of the LRB seismic isolation system, the displacements of the superstructure reduce significantly in the near filed earthquakes. In addition, by increasing the studied parameters, the absorbed energy of isolation system increases.

The increase in the yield strength and post yield stiffness ratio increase the acceleration of structure and base shear which lead to stronger structure. The result of study have shown that by choosing an optimum value for the yield strength and post yield stiffness ratio, the displacement of structure decreased without too much compromise in structural acceleration and base shear. This optimum values are: 0.8% - 1% of the total weight of the building for yield strength and 0.08 – 0.12 for the post yield stiffness ratio to initial stiffness of LRB.

Nomenclature

d = Diameter of the bearing, (cm)
h =Total height of the bearing, (cm)
N = Number of rubber layers, (Nos)
t =Thickness of individual layers, (cm)
d_p =Diameter of the lead core, (cm)
t_s =Thickness of steel plate, (cm)
N_s =Number of steel plates, (Nos)
T_{tp} =Thickness of top and bottom cover plates, (cm)
F_y =Yield force of bearing,
D_D = Design displacement,
K_{eff} = Effective stiffness,

W_D = Energy dissipated,
Q_d = Characteristic strength,
K_1 = Elastic stiffness,
K_2 = post elastic stiffness,
T_D= Design period,

Appendix

The basic design calculations of the building is as follows:

$W_{DL+LL} = 3078.5 ton W_{DL+LL}$: Total weight of building

$P_{DL+LL+EQ} = 182 ton\ P_{DL+LL+EQ}$: Maximum axial load of column

$$T_f = 0.7H^{\frac{3}{4}} = 0.7\times 21^{\frac{3}{4}} = 0.69\sec$$

$$T_D = 2.5\sec \ge 3T_f = 3\times 0.68 = 2.07\sec$$

$$D_D = \left(\frac{g}{4\pi^2}\right)\frac{Cv.T_D}{B_d} = \left(\frac{9.81}{4\pi^2}\right)\times\frac{0.64\times 2.5}{1.35} = 0.295m$$

$$K_{eff} = \frac{W_{DL+LL}}{g}\left(\frac{2\pi}{T_D}\right)^2 = \frac{3078.5}{9.81}\times\left(\frac{2\pi}{2.5}\right)^2 = 1980.2 ton/m$$

$$W_D = 2\pi k_{eff}.D_D{}^2.\beta_{eff}$$

$$= 2\times\pi\times 1980.5\times 0.295^2\times 0.15 = 162.4 ton.m$$

$$Q_d \cong \frac{W_D}{4D_D} = \frac{162.4}{4\times 0.295} = 137.6ton$$

$$k_2 = k_{eff} - \frac{Q_d}{D_D} = 1980.2 - \frac{137.6}{0.295} = 1513.7 ton/m$$

$$D_y = \frac{Q_d}{k_1 - k_2} = \frac{137.6}{9\times 1513.7} = 0.01m \qquad k_1 \approx 10k_2$$

$$A_{pb}^{total} = \frac{Q_d}{F_y^{pb}} = \frac{137.6}{1200} = 0.115m^2$$

$$A_{pb}^{n} = \frac{A_{pb}^{total}}{N} = \frac{0.115}{25} = 0.0046m^2$$

$$Q_d = A_{pb}^{total}.F_y = 0.196\times 1200 = 235ton$$

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