EFFECT OF THE DAMPING OF THE LRB SYSTEM ON THE DYNAMIC RESPONSE OF A BASE ISOLATED BUILDING

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ABSTRACT:

In order to illustrate the effect of damping on the response of a base-isolated building, a parametric study is led, taking into account the progressive variation of the damping ratio (08% to 35%) under different types of seismic excitations (near and far field). A time history analysis is used to determine the response of the structure in terms of relative displacement and understory drift at various levels of the building. The results show that the efficiency of the isolator increases with the assumed damping ratio, provided that this latter is less or equal to 20%. Beyond this value, the isolator becomes less convenient. Furthermore, a strong deviation of energy capacity by the LRB (Lead Rubber Bearing) system is recorded.

KEYWORDS: Damping, base isolation, LRB, seismic excitation, hysteresis.

1. INTRODUCTION

The approach of the technique of seismic isolation at the base and the technique of controlled response consists in controlling displacements and accelerations of structure therefore reducing the forces in these elements, by maintaining them in the elastic state with a level of almost zero damage non-structural elements, this technique allows an artificially lengthen of the natural period of structure in the low frequency with low energy seismic induced. The isolation system chosen in this study is the LRB system (Lead Rubber Bearing) which includes the following advantages: in one hand he plays the part of an isolator and in the other hand the dissipating of the energy. [9]

2. MODELING OF SYSTEM LRB

These systems exploit the principle of laminated bearing and its lateral flexibility. The isolation system LRB is similar to laminated rubber bearing with central hole into which the lead core is press-fitted as shown in Figure (1). The core of lead is used to provide additional energy dissipation; the ability to absorb energy from the lead core significantly reduces lateral displacement. The system becomes essentially a damper hysteresis device. The force deformation characteristics of the hysteretic damper can be modeled exactly by a set of coupled non-linear differential equations. Typical hysteresis loops, such as elastic-plastic, rigid friction, bi-linear and smooth hysteretic, are generated by attributing appropriate values to the variables of the differential equation. [4]

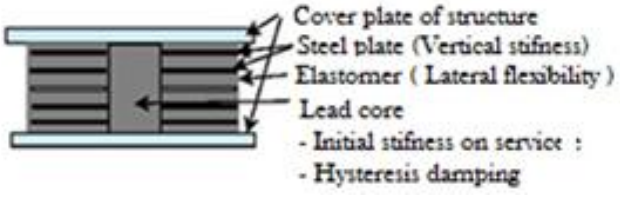

Figure 1. Component of LRB system

The mathematic model for LRB system is shown in Figure.(2a), and the force-deformation behavior is shown in Figure 2.b.

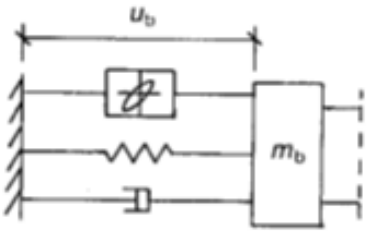

Figure 2. (a) Mathematic model for system LRB

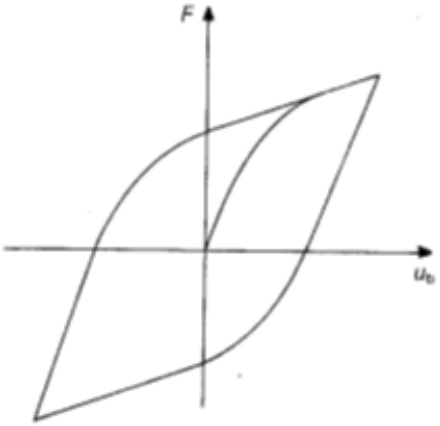

Figure 2. (b) Hysteresis loop force-deformation for system LRB

3. MODELING OF BASE-ISOLATED BUILDING

For the present study, the idealized mathematical model of the N story is shown in Figure (3a). The base-isolated building is modeled as a shear type structure mounted on isolation systems with two lateral degrees-of-freedom at each floor.

The following assumptions are made for the structural system under consideration:

1. During the earthquake excitation, The superstructure is considered to remain within the elastic limit, this assumption is valid with the presence of the isolator, which reduces the response of the structure considerably.
2. The floors are assumed to be rigid in its planes and the mass is supposed to be lumped at each floor level.
3. The columns are inextensible and weightless providing the lateral stiffness.
4. The system is subjected to two horizontal components of the earthquake ground motion.
5. The effects of soil-structure interaction are not taken into consideration.

For the system under consideration, the governing equations of motion are obtained by considering the equilibrium of forces at the location of each degrees of-freedom. The equations of motion for the superstructure under earthquake ground acceleration are expressed in the matrix form as:

$$[M_s]\{\ddot{x}_s\} + [C_s]\{\dot{x}_s\} + [K_s]\{x_s\} = -[M_s]\{r\}\left(\ddot{x}_b + \ddot{x}_g\right) \quad (1)$$

Where $[M_s]$, $[C_s]$, $[K_s]$, respectively are the mass, damping and stiffness matrices of the superstructure.
$\{x_s\} = \{x_1, x_2, x_3, \dots, x_n\}^T$, $\{\dot{x}_s\}$, $\{\ddot{x}_s\}$, are the unknown relative floor displacement, velocity and acceleration vectors, respectively
$\ddot{x}_b$, $\ddot{x}_g$: are the relative acceleration of base mass and earthquake ground acceleration, respectively
$\{r\}$, is the vector of influence coefficients.

The model structural of the isolated building is represented in Figure 3 (a) as follows.

Figure 3 (b) shows the equivalent linear model of the isolator

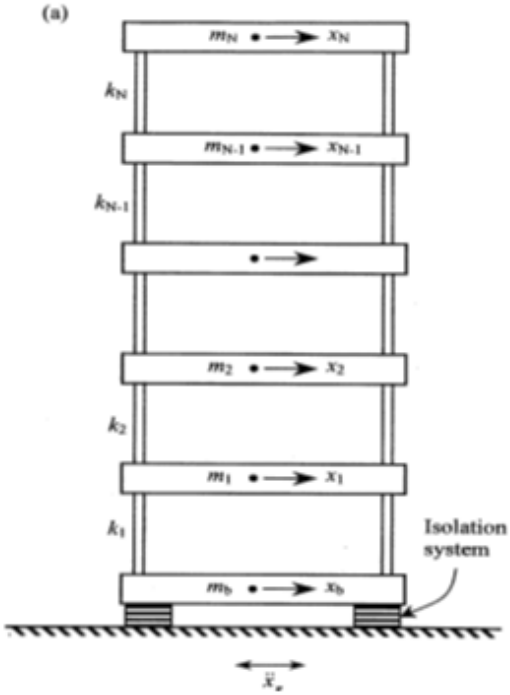

Figure 3. (a) Mathematic model

of the N-story base-isolated building

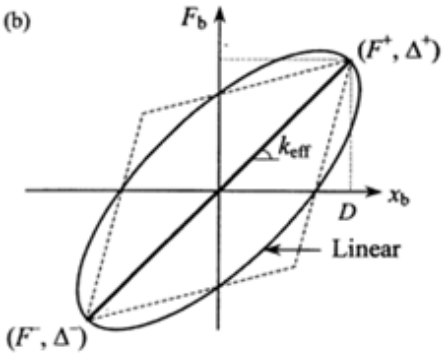

Figure 3. (b) Equivalent linear model for isolator LRB

The corresponding equation of motion for the base mass under earthquake ground acceleration is expressed by:

$$m_b\ddot{x}_b + F_b - k_1x_1 - c_1\dot{x}_1 = -m_b\ddot{x}_g \quad (2)$$

m_b, F_b : are the base mass and restoring force developed in the isolation system, respectively.

k_1 : is the story stiffness of first floor; and c_1 : is the first story damping.

The restoring force developed in the isolation system Fb depends upon the type of isolation system considered and the approximate numerical models shall be used.

4. MATHEMATIC MODEL FOR LRB SYSTEM

For the present study, the force-deformation behavior of the isolator is modeled by: the equivalent linear elastic–viscous damping model for the non-linear systems.
As per Uniform Building Code [7] and international Building Code [8], the non-linear force-deformation characteristic of the isolator can be replaced by an equivalent linear model through effective elastic stiffness and effective viscous damping. The linear force developed in the isolation system can be expressed as:

$$F_b = K_{eff}x_b + C_{eff}\dot{x}_b \quad (3)$$

Where: K_{eff} is effective stiffness,

$$C_{eff} = 2\beta_{eff} M \omega_{eff} \quad (4)$$

C_{eff} , is the effective viscous damping constant.

β_{eff} , is the effective viscous damping ratio;

$$\omega_{eff} = \frac{2\pi}{T_{eff}} \quad (5)$$

ω_{eff}, is the effective isolation frequency;

$$T_{eff} = 2\pi \sqrt{M/K_{eff}} \quad (6)$$

T_{eff} is the effective isolation period.

The equivalent linear elastic stiffness for each cycle of loading is calculated from the curve force-deformation of the isolator obtained experimentally and expressed mathematically as:

$$K_{eff} = \frac{F^+ - F^-}{\Delta^+ - \Delta^-} \quad (7)$$

Where F^+ et F^- are the positive and negative forces at test displacements Δ^+, Δ^- respectively. Thus, the K_{eff} is the slope of the peak-to-peak values of the hysteresis loop as shown in Figure.(2b)

The effective viscous damping of the isolator unit calculated for each cycle of loading is specified as:

$$\beta_{eff} = \frac{2}{\pi}\left[\frac{E_{loop}}{K_{eff}(|\Delta^+| - |\Delta^-|)^2}\right] \quad (8)$$

Where: E_{loop} is the energy dissipation per cycle of loading.

At a specified design isolation displacement, D, the effective stiffness and damping ratio for a bi-linear system are expressed as:

$$K_{eff} = K_b + \frac{Q}{D} \quad (9)$$

$$\beta_{eff} = \frac{4Q(D-q)}{2\pi K_{eff} D^2} \quad (10)$$

5. SOLUTION OF MOTION EQUATIONS

In this situation Classical modal superposition technique cannot be employed in the solution of equations of motion here because,

1. The system is non-classically damped because of the difference in the damping in isolation system compared to the damping in the superstructure,

2. The force-deformation behavior for the isolation systems considered is non-linear.

Therefore, the equations of motion are solved numerically using Newmark's method of step-by-step integration; adopting linear variation of acceleration over a small time interval of Δt. The time interval for solving the equations of motion is taken as 0.02/200 s (i.e. $\Delta t = 0.0001\ s$)

6. PARAMETRIC STUDY

To illustrate the effect of damping on the response of a building with base isolation, an extensive investigation was undertaken.

A building of reinforced concrete of eight stories with a rectangular plan of 12 × 24 m is considered, with four bays in the longitudinal direction and two bays in the transverse direction spacing of 6 m. Section of the beams are 30 × 60 cm ², section of the columns are 50 × 50 cm ² and the floor height is 3 m with solid slabs 18 cm thick:

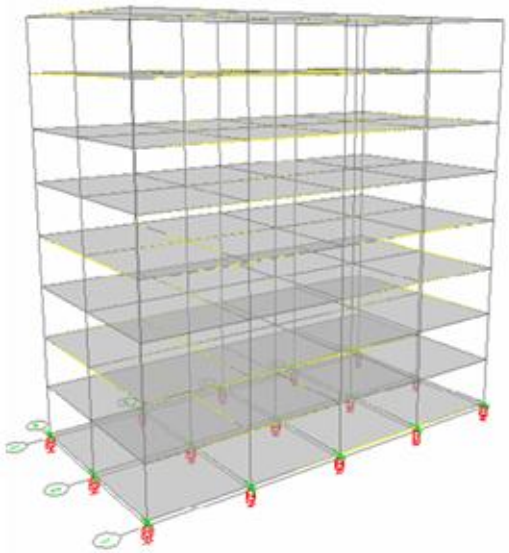

Figure 4. (2) 3D view of the isolated structure

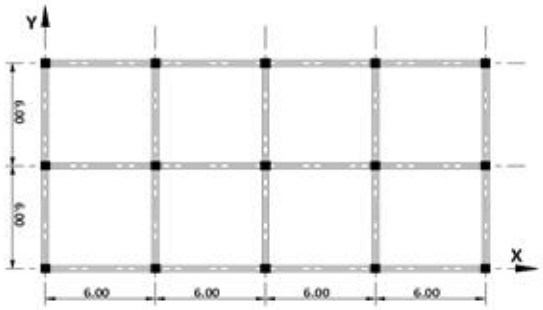

Figure 4. (1) Plan view of the isolated structure

Seismic excitations considered in this study are:

- Component of El Centro Imperial Valley earthquake (1979).
- Component Outer Harbor Wharf in Oakland Loma Prieta Earthquake (1989).
- The component of Lexington Dam Loma Prieta Earthquake (1989).
- The component of the Sylmar County Northridge earthquake (1994).

With peak ground acceleration (Peak Ground Acceleration) PGA 0436 g, 0287 g, 0442 g and 0604 g respectively. Accelerograms of these excitations respectively shown in Figures 5, 6, 7 and 8

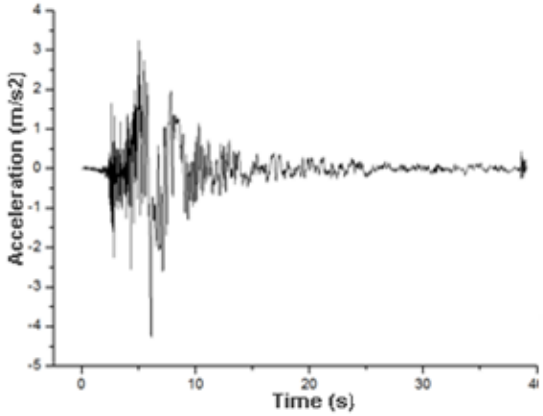

Figure 5. The component accelerograms of El Centro Imperial Valley earthquake (1979)

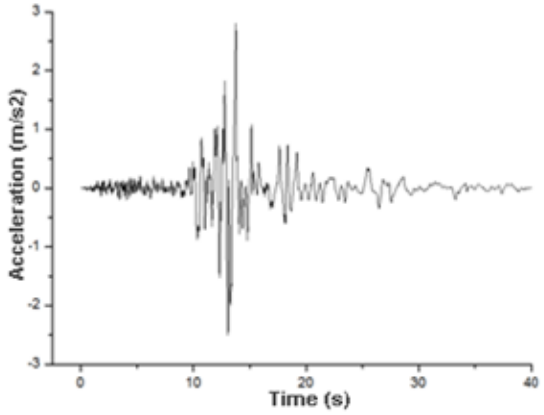

Figure 6. The component accelerograms of Oakland Outer Loma Prieta Earthquake (1989).

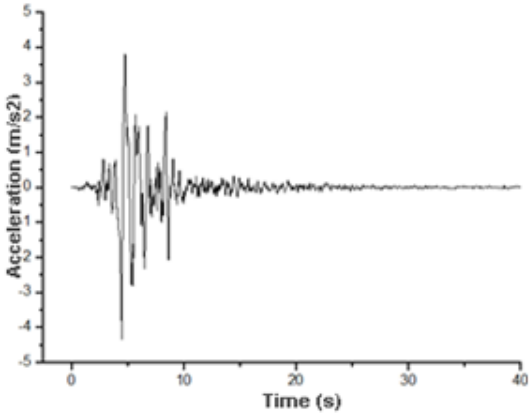

Figure 7. Component Accelerogram 0 degrees of Lexington Dam Loma Prieta earthquake

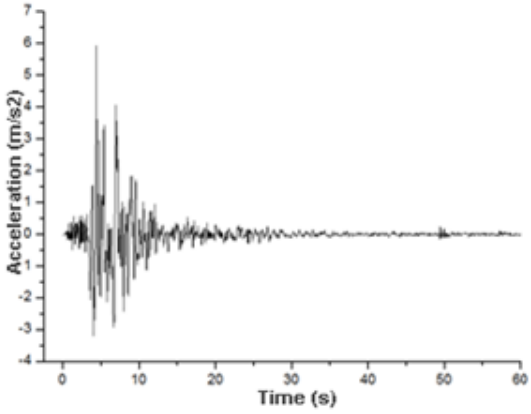

Figure 8. The component accelerograms of the Sylmar County Northridge earthquake (1994).

The frequency analysis of these accelerograms showed that the frequency ranges of each seismic excitation are distributed as follows:

- Component of El Centro Imperial Valley: 0.15 to 0.5Hz.
- Component Outer Harbor Wharf in Oakland Loma Prieta: 0.5 to 1.65Hz.
- The component of Lexington Dam Loma Prieta: 0.65 to 2.45Hz.
- Component of Northridge Sylmar County: 0.35 to 3.6Hz.

The Fourier amplitude spectra of seismic excitations are given by Figures 9, 10, 11 and 12 the following:

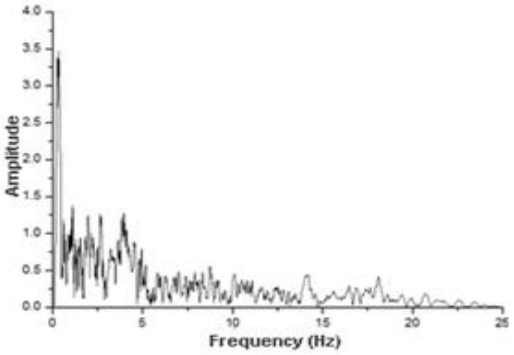

Figure 9. Contents of the frequency component of El Centro Imperial Valley earthquake

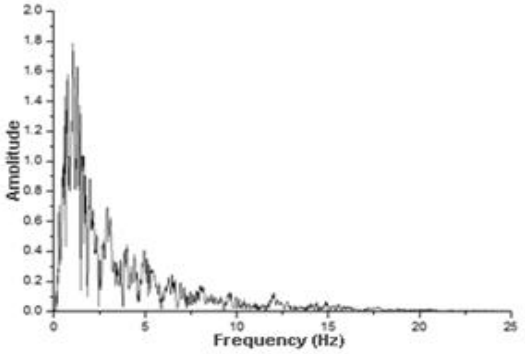

Figure 10. The frequency content of Oakland Outer component of the Loma Prieta earthquake

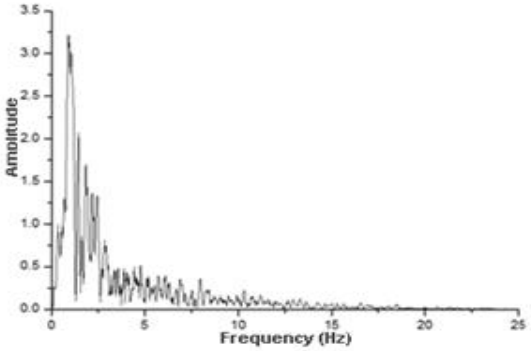

Figure 11. The frequency content of component Lexington Dam Loma Prieta Earthquake.

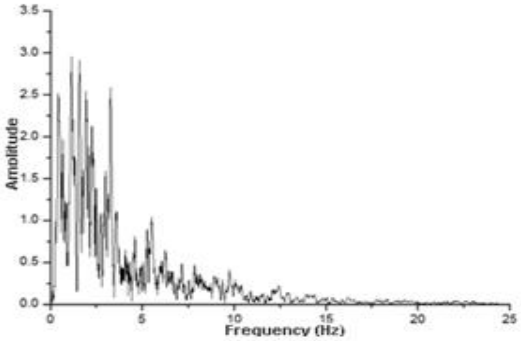

Figure 12. The frequency content of Sylmar County component of the Northridge earthquake

The numerical simulation has been prepared by ETABS V9 software, produced by the firm Computers and Structures, University of Berkekey USA.

7. RESULTS

The results of the comparison of the maximum responses of the structure isolated under various percentages of effective damping from the isolation system of account from the various seismic excitations will be represented in the following Figures

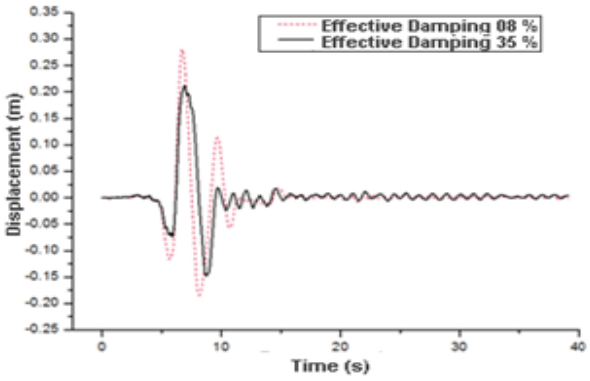

Figure 13. Comparison of absolute displacements of the last level with low effective damping ratio (8%) and high (35%) subjected to the component of El Centro Imperial Valley Earthquake

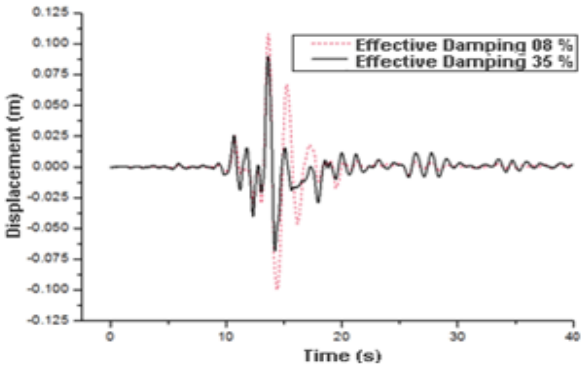

Figure 14. Comparison of absolute displacements of the last level with low effective damping ratio (8%) and high (35%) subject to the component Oakland Outer Loma Prieta Earthquake

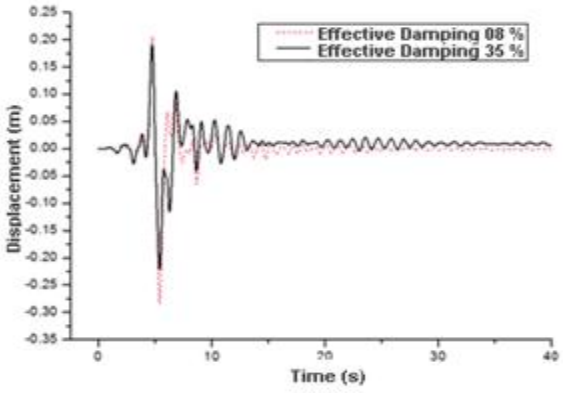

Figure 15. Comparison of absolute displacements of the last level with low effective damping ratio (8%) and high (35%) subjected to the component of Lexington Dam Loma Prieta earthquake

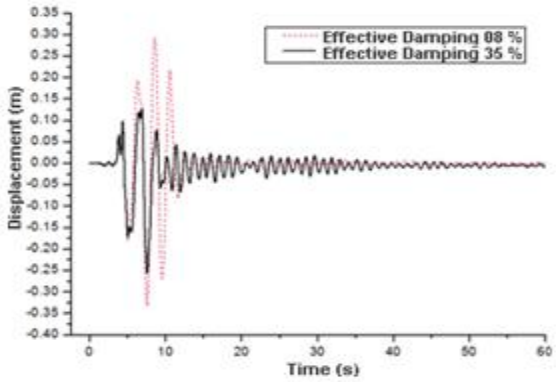

Figure 16. Comparison of absolute displacements of the last level with low effective damping ratio (8%) and high (35%) subjected to the component of the Sylmar County Northridge earthquake

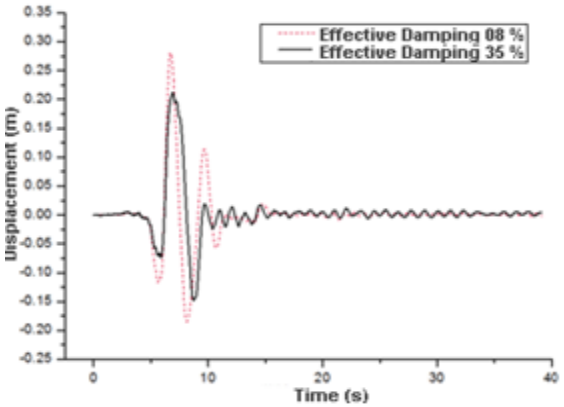

Figure 17. Comparison of absolute displacements of the isolation system with low effective damping ratio (8%) and high (35%) subjected to the omponent of El Centro Imperial Valley earthquake.

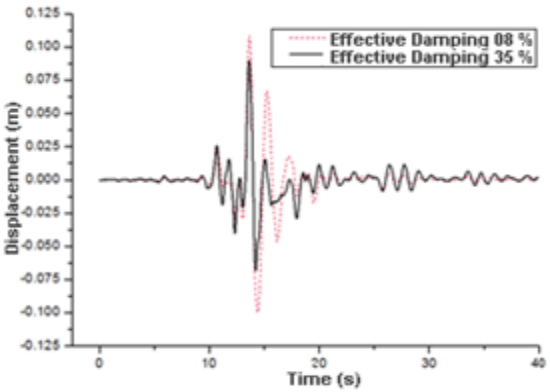

Figure 18. Comparison of absolute displacements of the isolation system with low effective damping ratio (8%) and high (35%) subjected to the component of Oakland Outer Loma Prieta earthquake

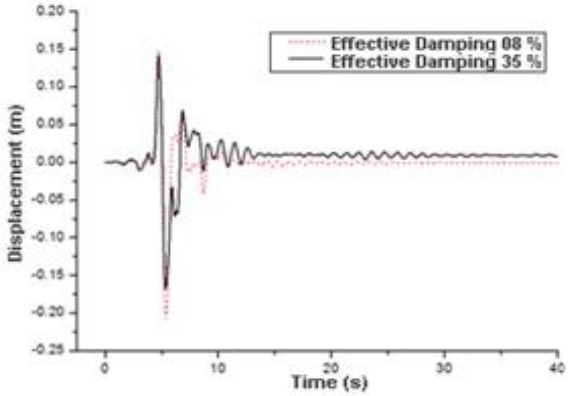

Figure 19**.** Comparison of absolute displacements of the isolation system with low effective damping ratio (8%) and high (35 subjected to the component of Lexington Dam Loma Prieta earthquake

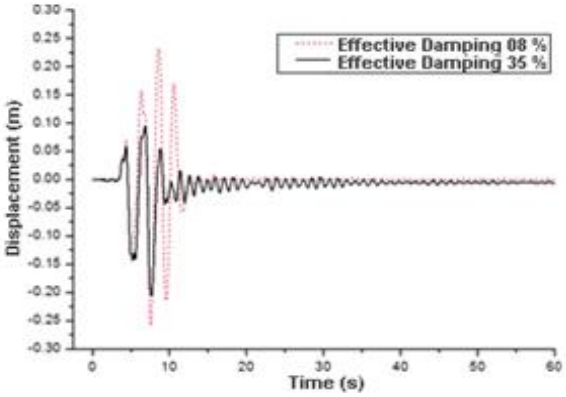

Figure 20. Comparison of absolute displacements of the isolation system with low effective damping ratio (8%) and high (35%) subjected to the component of Sylmar County Northridge earthquake

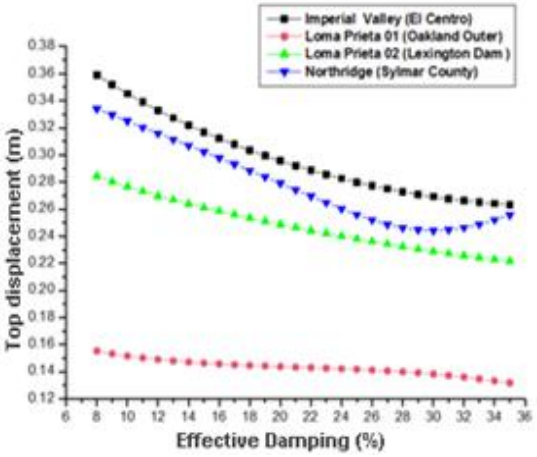

Figure 21. Absolute maximum displacements of the 8th level with different effective damping ratio

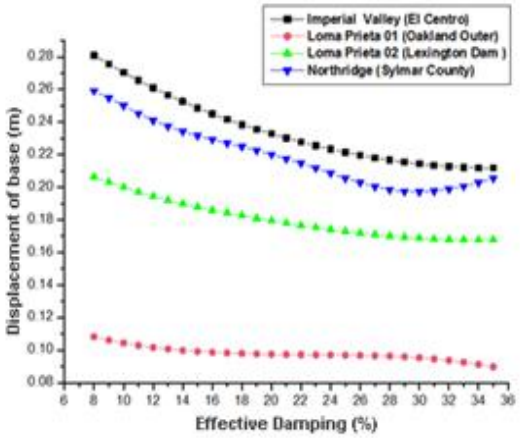

Figure 22**.** Absolute maximum displacements of the base level with different effective damping ratio

8. INTERPRETATIONS

8.1. Displacements

According to the charts (Figure 13 to 22), we note that relative displacements of the superstructure or absolute displacements to the base for an isolated structure are decreased considerably by the increase in effective damping for any seismic excitation envisaged in the study; that is due to the presence of lead core for LRB system which resists the shear strains.

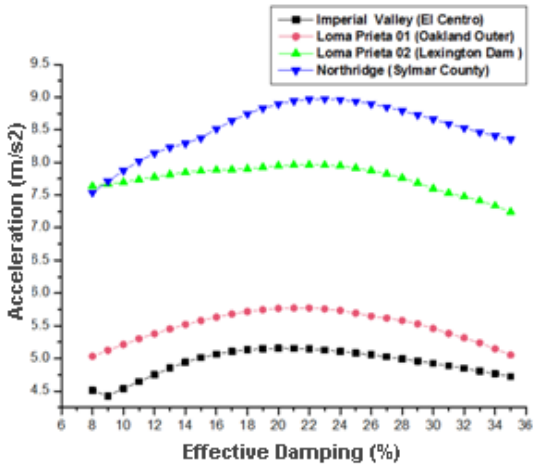

Figure 23. Maximum accelerations of the 8th level with different effective damping ratio

8.2. Acceleration

From Figureure 23, it is observed that the peak accelerations transmitted are increased in the range of 08 to 20% of the effective damping; contrary, over 20% we recorded a reduction of the accelerations transmitted and that for all seismic excitations

This is reflected by the change in the total shear strength of the isolator, for different values of the effective damping, it was mentioned that: $K_{eff} = K_d + \frac{Q}{D}$ so

: $F_m = F_d + Q$.

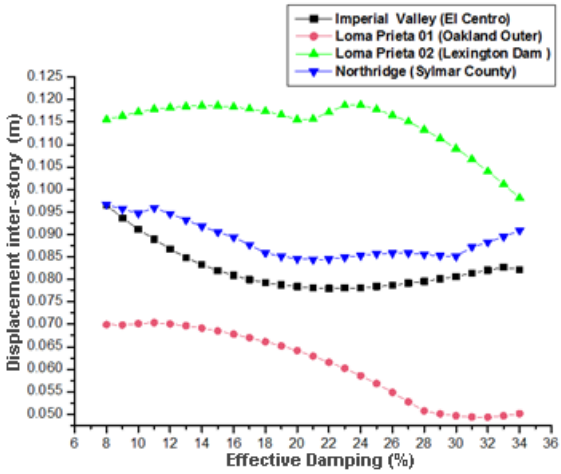

Figure 24. Maximum accelerations of the base level with different effective damping ratio

9. CONCLUSION

This research focuses an investigating of the response of an isolated building, a parametric study of eight story building based isolation mounted on an isolation system with are made of alternating layers of steel plates and natural rubber with a central hole into which the lead core (Lead Rubber Bearings) (LRB) is performed in order to control the deformation of the isolator and therefore the absolute displacements , interstory drift and acceleration of the superstructure. In this study an incremental progressive variation of damping (8% to 35%), under various earthquake ground excitations was undertaken.

Based on the numerical results of the parametric study, the following conclusions can be drawn.

- The relative displacements of the superstructure or absolute isolation of the system are reduced with the increase in effective damping under various earthquake ground excitations
- The accelerations transmitted to the superstructure are increased for a low effective damping , contrary to a damping medium at strong, they are reduced considerably.
- The inter-story drift for all seismic loads used are generally reduced with increasing the rate of the effective damping.

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