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Effects of the Damping on the Seismic Response of a Base Isolated Building

Hadj Mohamed OUNIS [1,*], Abdelhafid OUNIS [2], Mohamed Zoheir KAAB [2]

ABSTRACT [ENGLISH/ANGLAIS]

To illustrate the effect of damping on the response of a building with base isolation of type LRB, a very broad investigation was undertaken. It consisted of a parametric study which mainly takes account of the progressive variation of the damping rate (from 8% to 35%) under different types of seismic excitations. Using a time history analysis of displacements and accelerations at various levels of the structure, the results showed that with a small percentage of damping (8%), the isolator becomes less powerful, as opposed to high damping (35%), where it is satisfactory.

Keywords: Damping, Base isolation, LRB, Seismic excitation

RÉSUMÉ [FRANÇAIS/FRENCH]

Pour illustrer l'effet d'amortissement sur la réponse d'un bâtiment avec isolation à la base du LRB type, une enquête très large a été entrepris. Il s'agissait d'une étude paramétrique qui prend essentiellement en compte de la variation progressive du tauxd'amortissement (de 8% à 35%) sous différents types d'excitations sismiques. En utilisant une analyse historique de temps de déplacements et les accélérations à différents niveaux de la structure, les résultats ont montré que, avec un petit pourcentage d'amortissement (8%), l'isolateur devient moins puissant, par opposition à amortissement élevé (35%), où il est satisfaisante.

Mots-clés: D'amortissement, d'isolation de base, LRB, l'excitation sismique

Affiliations:

[1] Department of Civil Engineering, University of Batna, ALGERIA

[2] Department of Civil Engineering, University of Biskra ALGERIA

Email Address for Correspondence/ Adresse de courriel pour la correspondance: ounis_hm@yahoo.fr

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INTRODUCTION

The approach to the technique of seismic isolation at the base and the technique of controlled response aims to control 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 in non-structural elements; This technique allows to artificially lengthen the natural period of structure in the low frequency with low induced seismic energy. The isolation system chosen in this study is the LRB system (Lead Rubber Bearing) which has the advantages: of acting like while dissipating energy [1].

MODELING OF THE LRB SYSTEM

These systems exploit the principle of the laminated bearing and its lateral flexibility. The LRB isolation system is similar to a laminated rubber bearing with a 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; which significantly reduces lateral displacements. 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 [2].

FIGURE 1

Figure 1 shows the components of the LRB system

The LRB system is shown in figure 2 the schematic model is shown in figure 2b and the force-deformation behavior is shown in figure 2c.

FIGURE 2a

Figure 2a shows the Lead rubber bearing

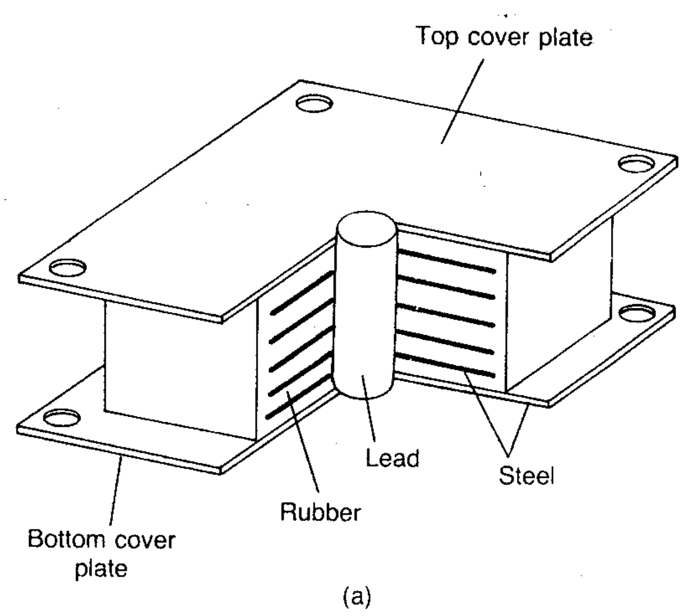


FIGURE 2b

Figure 2b shows the mathematical model of the LRB system

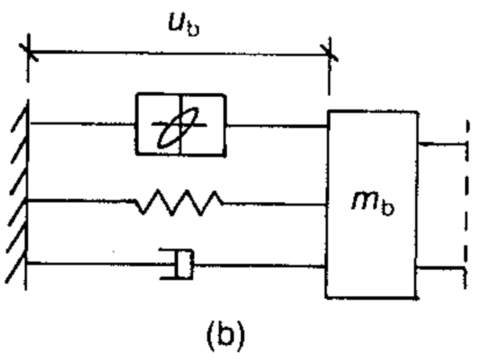
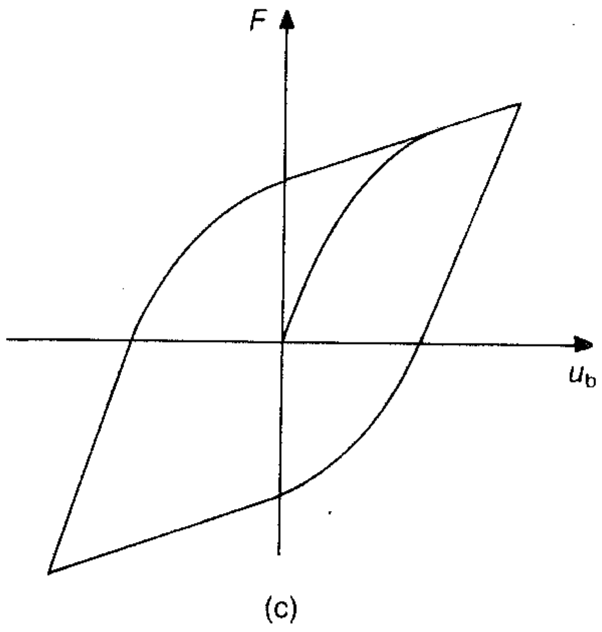


FIGURE 2c

Figure 2c shows the Hysteresis loop force-deformation for the LRB system



MODELING OF THE BASE-ISOLATED BUILDING

For the present study, the idealized mathematical model of the N story structure 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 in the presence of the isolator, which reduces the response of the structure considerably.
2. The floors are assumed to be rigid in their planes and the mass is supposed to be lumped at each floor level.
3. The columns are inextensible and weightless, and provide 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 degree of freedom. The equations of motion for the superstructure under earthquake ground acceleration are expressed in the matrix form as:

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

Where

$[M_s]$, $[C_s]$, $[K_s]$, are respectively the mass, damping and stiffness matrices of the superstructure.

$\{x_s\} = \{x_1, x_2, x_3, \dots, x_n\}^T$, $\{\dot{x}_s\}$, $and\ \{\ddot{x}_s\}$, are the unknown relative floor displacement, velocity and acceleration vectors, respectively

$\ddot{x}_b$, and $\ddot{x}_g$: are the relative acceleration of the base mass and earthquake ground acceleration, respectively

$\{r\}$, is the vector of influence coefficients.

The structural model of the isolated building is represented in figure 3a below.

FIGURE 3a

Figure 3b shows the equivalent linear model of the isolator (Mathematical model of the N-story base-isolated building)

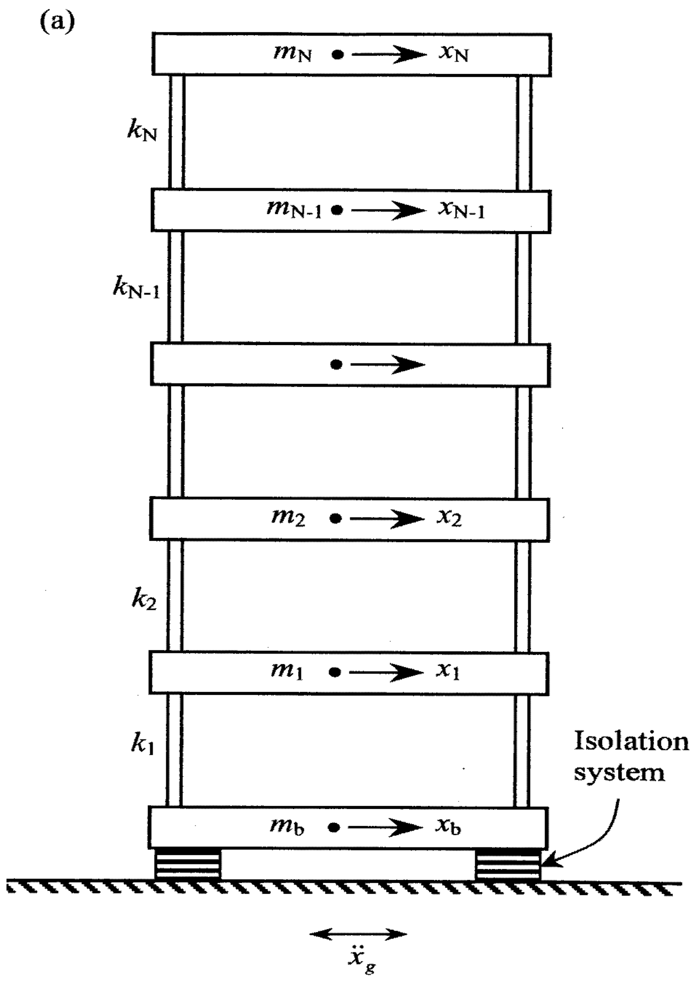
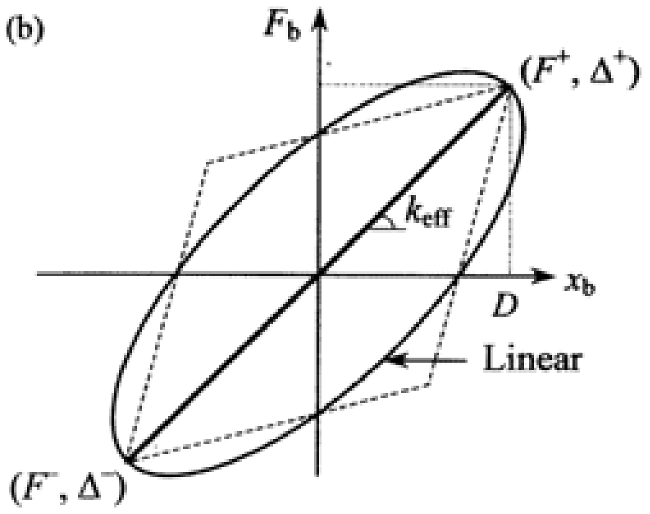


FIGURE 3a

Figure 3b shows the equivalent linear model for the LRB isolator



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 on the approximate numerical models used.

MATHEMATICAL MODEL OF THE 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 [3] and international Building Code [4], 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,

$$C_{eff} = 2\beta_{eff}M\omega_{eff} \quad [4]$$

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^+ and F^- are the positive and negative forces at test displacements Δ^+ and 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:

$$K_{eff} = K_b + \frac{Q}{D} \quad [9],$$

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

SOLUTION OF MOTION EQUATIONS

In this situation the 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 damping in the isolation system and in the superstructure

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

Therefore, the equations of motion are solved numerically using New mark'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).

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. Sections of the beams are 30 × 60 cm ^{2}, sections of the columns are 50 × 50 cm ^{2} and the floor height is 3 m with solid slabs 18 cm thick:

FIGURE 4a

Figure 4a shows the **view of the isolated structure**

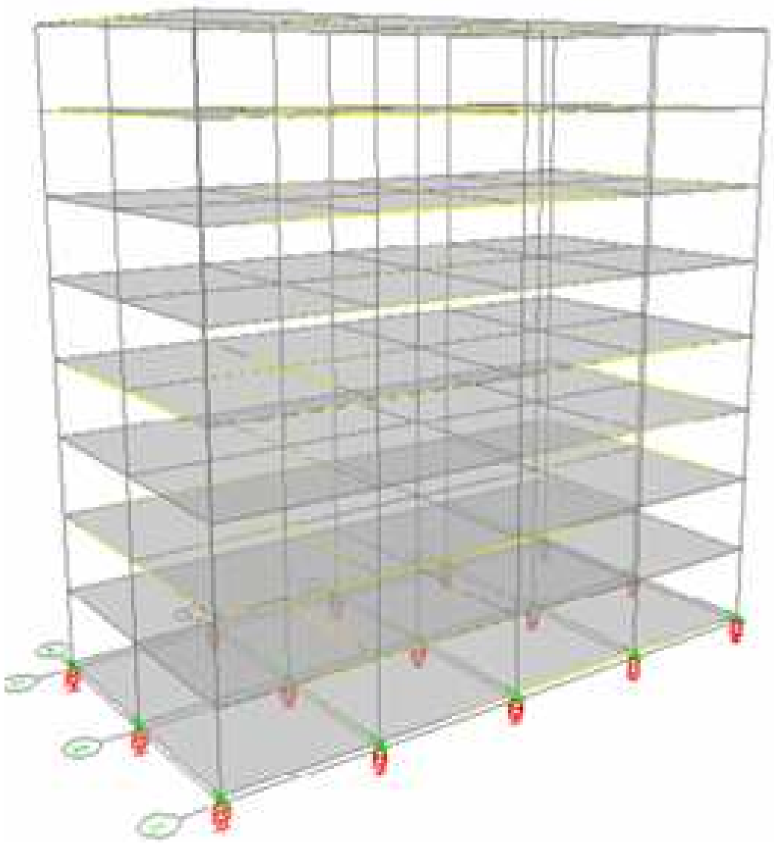
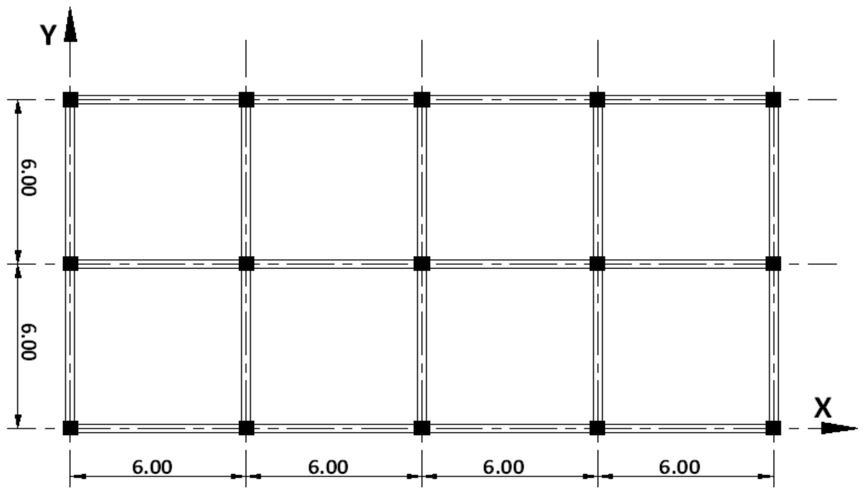


FIGURE 4b

Figure 4b shows the plan **view of the isolated structure**



The 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); component of Lexington Dam Loma Prieta Earthquake (1989); and component of Sylmar County Northridge earthquake (1994); with peak ground acceleration (PGA) of 0436 g, 0287 g, 0442 g and 0604 g respectively.

The numerical simulation was run using ETABS V9 software, produced by the firm Computers and Structures, University of Berkeley USA

RESULTS

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

FIGURE 5

Figure 5 shows the comparison of absolute displacements of the last level with low (8%) and high (35%) effective damping ratio subjected to the component of El Centro Imperial Valley Earthquake

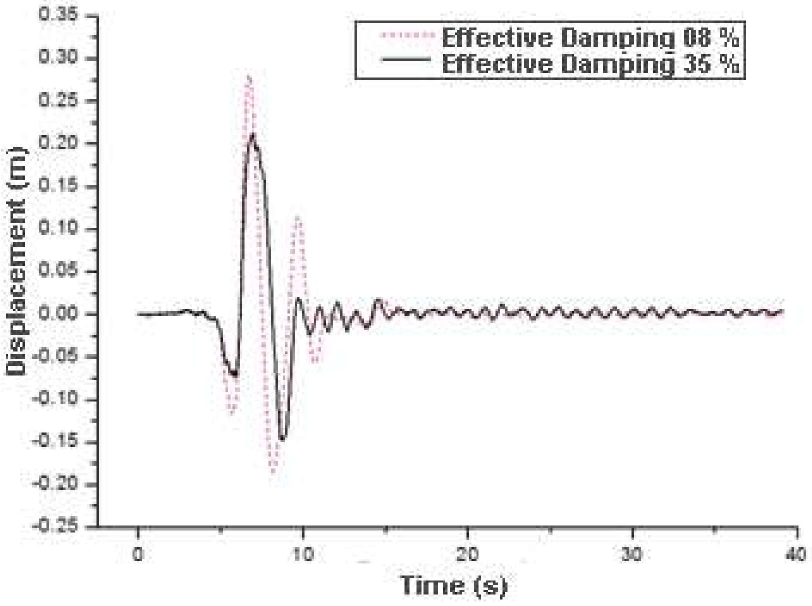


FIGURE 6

Figure 6 shows the comparison of absolute displacements of the last level with low (8%) and high (35%) effective damping ratio subject to the component of Oakland Outer Loma Prieta Earthquake.

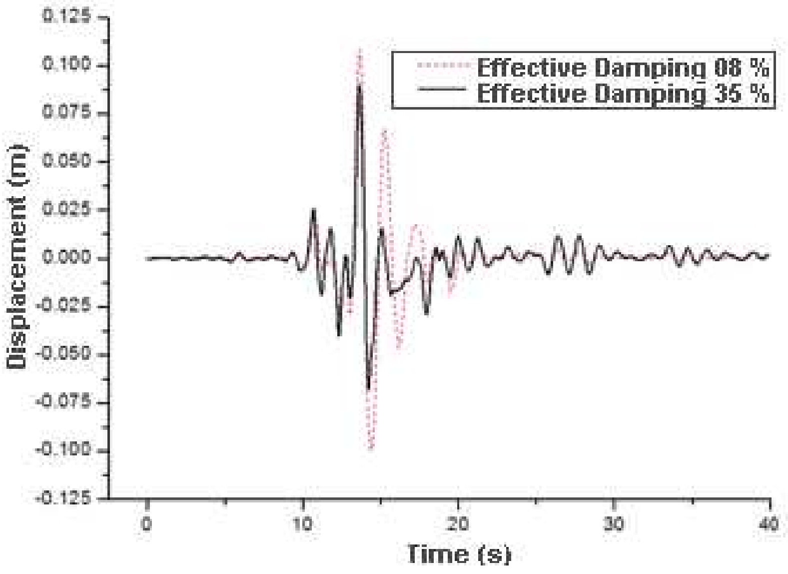


FIGURE 7

Figure 7 shows the Comparison of absolute displacements of the last level with low (8%) and high (35%) effective damping ratio subjected to the component of Lexington Dam Loma Prieta earthquake

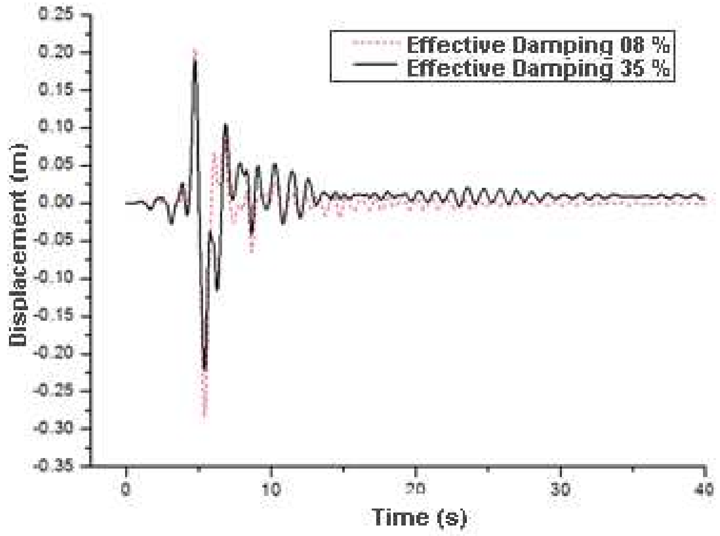


FIGURE 8

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

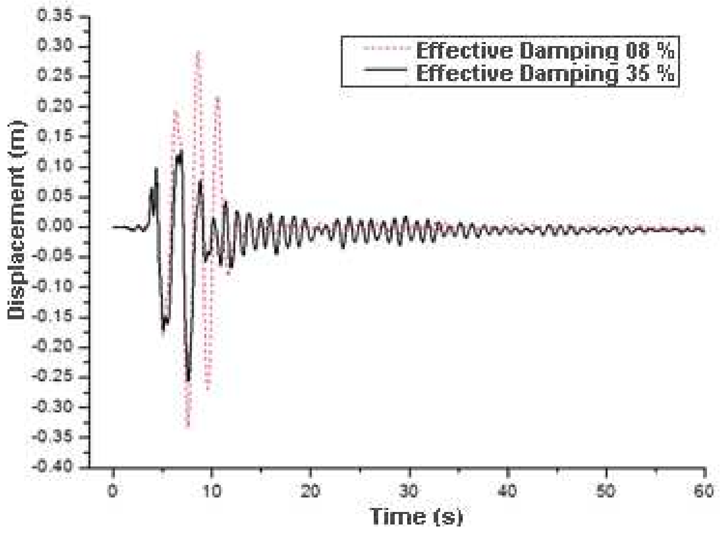


FIGURE 9

Figure 9 shows the comparison of absolute displacements of the isolation system with low (8%) and high (35%) effective damping ratio subjected to the component of El Centro Imperial Valley earthquake.

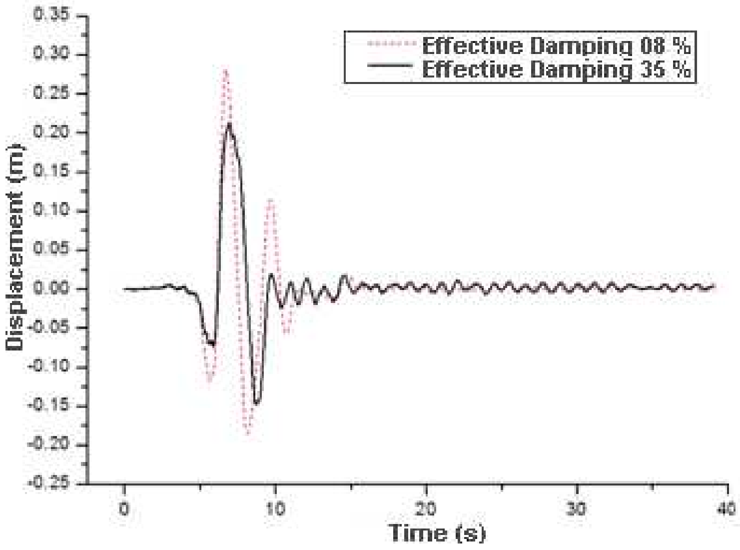


FIGURE 10

Figure 10 shows the comparison of absolute displacements of the isolation system with low (8%) and high (35%) effective damping ratio subjected to the component of Oakland Outer Loma Prieta earthquake

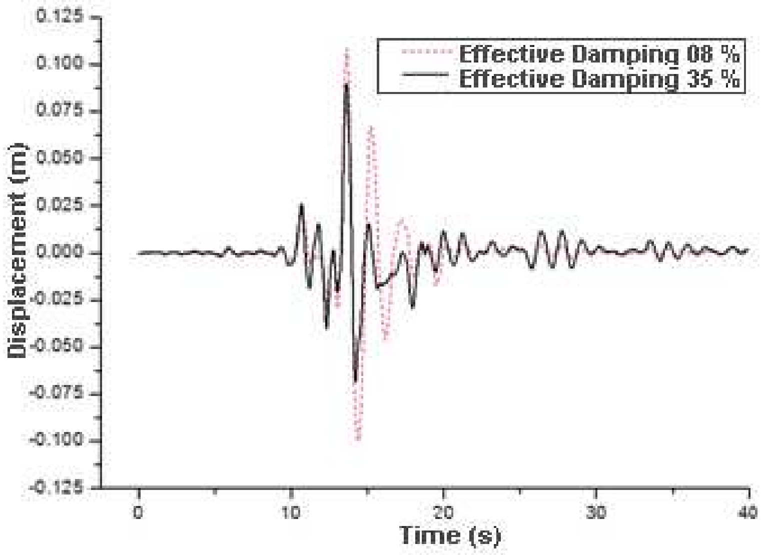
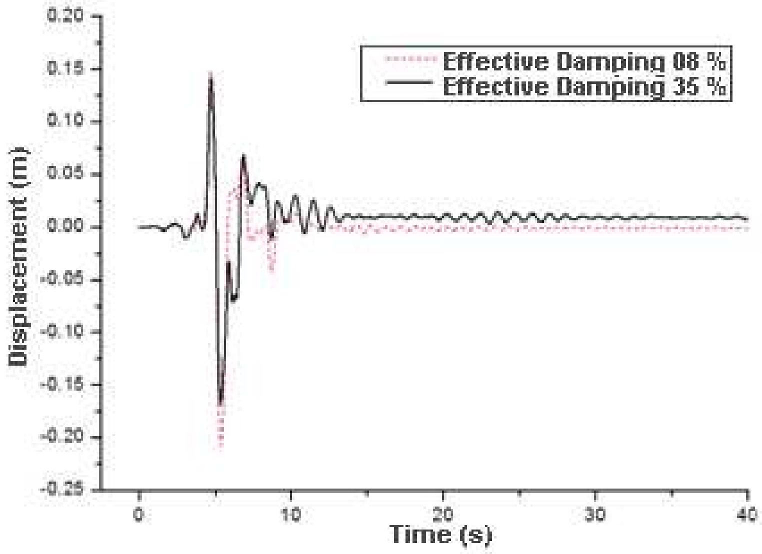


FIGURE 11

Figure 11 shows the comparison of absolute displacements of the isolation system with low (8%) and high (35) effective damping ratio subjected to the component of Lexington Dam Loma Prieta earthquake



INTERPRETATIONS

Displacements

From the charts (Figure 5 to 14), we note that the relative displacements of the superstructure or absolute displacements at the base for an isolated structure are considerably decreased by increasing the effective damping for all planned seismic excitation in the study; this is due to the presence of a lead core for LRB system which resists the shear strains.

FIGURE 12

Figure 12 shows the comparison of absolute displacements of the isolation system with low effective damping ratio (8%) and high (35%) effective damping ratio subjected to the component of Sylmar County Northridge Earthquake

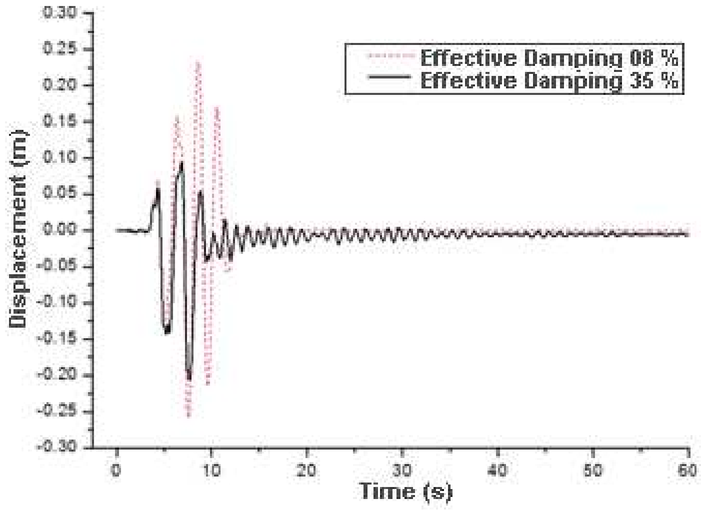


FIGURE 13

Figure 13 shows the absolute maximum displacements of the 8th level with different effective damping ratios

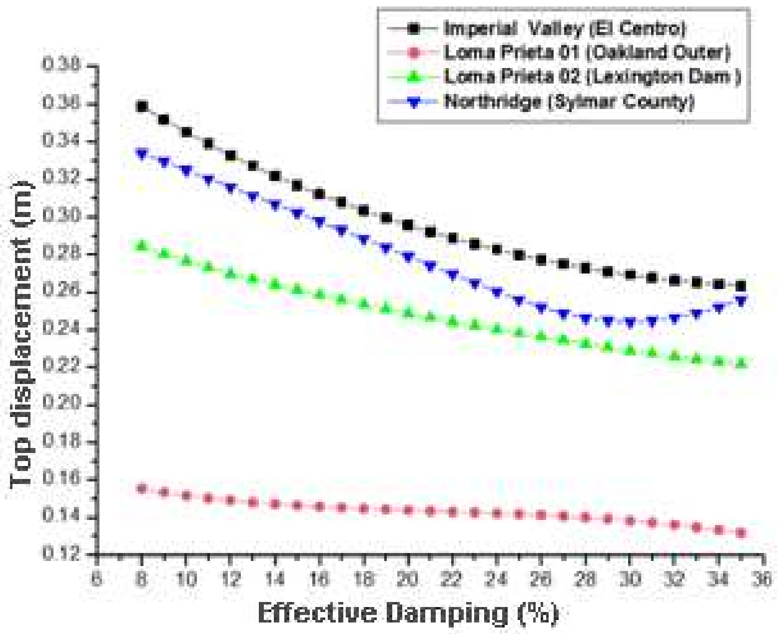


FIGURE 14

Figure 14 shows the absolute maximum displacements of the base level with different effective damping ratios

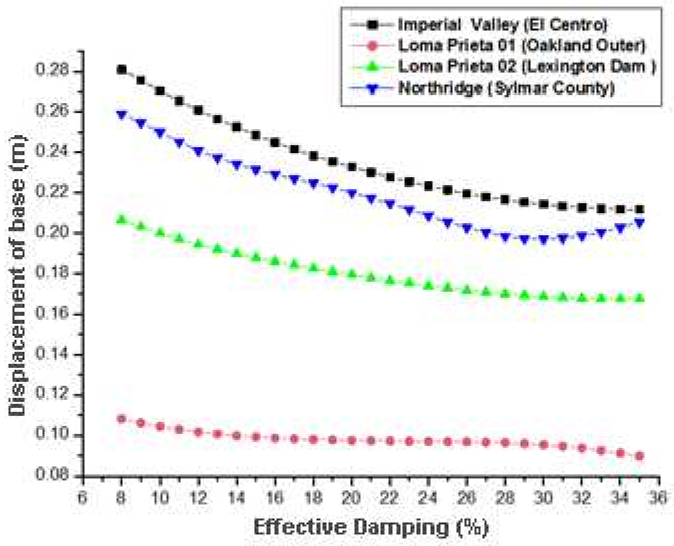
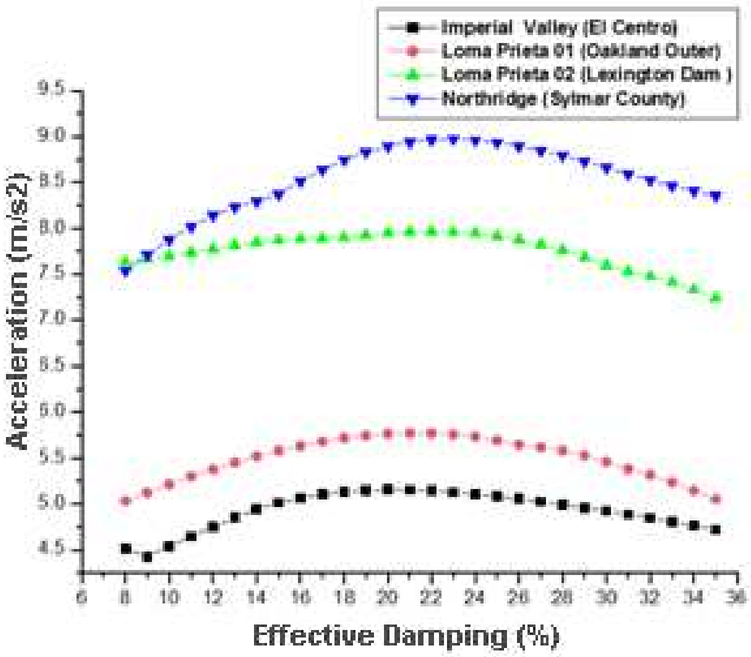


FIGURE 15

Figure 15 shows the maximum accelerations of the 8th level with different effective damping ratios



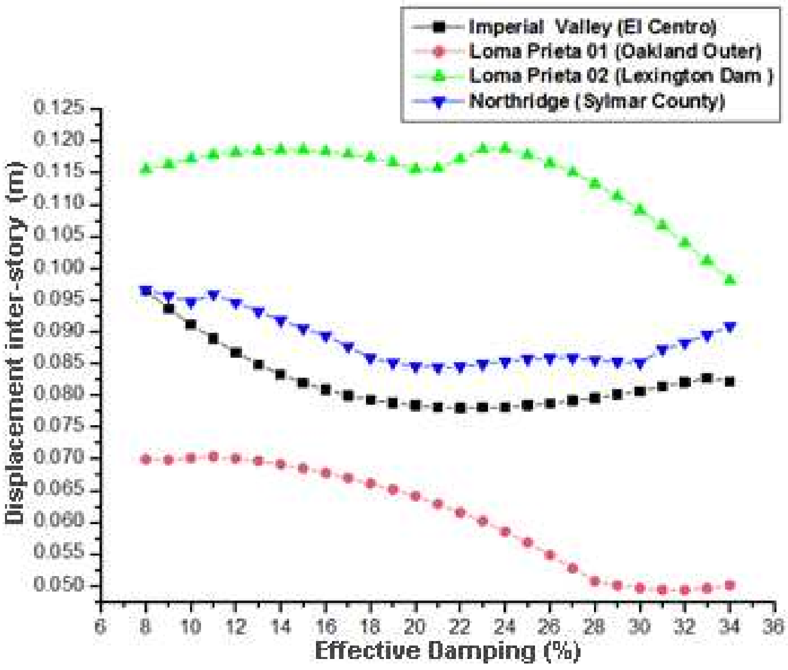
Acceleration

From Figure 15, it is observed that, for all seismic excitations the peak transmitted accelerations are increase when the effective damping is between 08 and 20% and decrease when it is over 20%.

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

FIGURE 16

Figure 16 shows the maximum accelerations of the base level with different effective damping ratio



CONCLUSION

This research focuses on investigating the response of an isolated building, through a parametric study of an 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 press-fitted 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, while they are considerably decreased under moderate to strong damping.
- The inter-story drift for all seismic loads used are generally reduced by increasing the rate of the effective damping

REFERENCES

[1] D.Lagab, Isolation à la base et réponse sismique contrôlées, proceeding mai 2009.

[2] R.S Jangid,. Seismic behavior of base isolated building: state of the art Proceedings of the Institution of civil Engineers.Structures & Buildings. 1995, 110 May, 186-203.

[3] Uniform Building Code, International conference of building officials, California: Whittier, 1997.

[4] International Building Code, International code council, 2000.

[5] Yeong-Bin Y, Kuo-Chun C. Base Isolation. Earthquake engineering Handbook. page 823-853

[6] Kelly JM,. Aseismic Base Isolation: Review and Bibliography. Soil Dynamics Earthquake Engineering. 1986;11:135–46.

[7] Naiem F, Kelly JM. Design of Seismic Isolated Structures. John Wiley & Sons, New York.1999

[8] Vasant A, Matsagar, R.S Jangid. Influence of isolator characteristics on the response of base-isolated structures.

[9] Anil KC. Dynamics of Structures Theory and Applications to Earthquake Engineering.(2nd Edition). New Jersey, Prentice Hall, 2005.

[10] Trevor and Kelly, Base Isolation of structure-Design Guidelines, New Zeland, S,E. Holmes Consulting Group Ltd , July 2001.

[11] Computer and structures , Inc, ETABS Computer Program V9 , Berkeley, California, USA.

[12] Fa-Gung Fan, goodarz Ahmadi. Seismic responses of secondary systems in base-isolated structures. Eng Struct 1992, vol 14 N° 1 page 35- 48.

[13] Ajay S, Jangid S. Behavior of Base-Isolated Structures with High Initial Isolator Stiffness, International Journal of Engineering and Applied Sciences 5:3 2009.

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CONFLICT OF INTEREST

No conflict of interest was declared by authors.

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