INFLUENCE OF THE DAMPING OF THE SEISMIC ISOLATION SYSTEM LRB ON THE ABSORBED ENERGY OF THE ISOLATED STRUCTURES

M.Z. Kaab[1], A. Ounis[2], D. Hamadi[2] and B. Athamnia[2]

[1] *Hydraulics Department, University of El-Oued, Algeria*
[2] *Civil Eng. and Hydraulics Department, University of Biskra, Algeria*
Email: kaab.mohamed@yahoo.fr

ABSTRACT:

To limit the loss of human life due to the collapse of many structures subjected to an earthquake, we can use devices characterized by a big horizontal flexibility and vertical rigidity, they are placed between the foundation and the superstructure to dissipate energy before the latter is transferred to the superstructure. We call these devices seismic isolators. The use of the isolation device LRB (Lead Rubber Bearings) allows to dissipate the maximum of energy and to control the deformations that are localized at the level of the latter. Therefore, a comparative study on the effective damping of the isolation system realized in this work was used to assess the influence of the damping of this seismic isolation system on the dynamic response of isolated structures in terms of absorbed energy.
The results of the dynamic response of isolated structures in terms of absorbed energy obtained by the comparative study on the low and high effective damping of the seismic isolation system LRB allowed us to deduce that the increase of the effective damping percentages reduces the input seismic energy and the energy of the modal damping and an increase of the energy absorbed by the isolation system.

KEYWORDS: Seismic base isolation, lead rubber bearing LRB, damping, absorbed energy.

1. INTRODUCTION

Seismic isolation systems are used during the last two decades to improve the seismic performance of buildings and reduce the potential damages to them by absorbing a significant amount of the energy produced in a structure during an earthquake.
To illustrate the influence of damping of seismic isolation system on the absorbed energy of the isolated structures, a parametric analysis was performed on an isolated structure of 08 levels for shrink rubber isolation system with a damper in bar LRB lead. This damping mechanism is based on the lead slug embedded within elastomeric isolators in order to control the deformation of the insulator and therefore the absorbed energy. This isolation system has different percentages of effective damping of 8% to 35% for the same isolated structure and under different seismic excitations.

2. EQUATION OF MOTION IN TERMS OF ENERGY

The equation of motion for an isolated structure in terms of displacements is given as follows:

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = -Mr\ddot{x}_g(t) \quad (1)$$

Where M is the mass matrix, C is the matrix of the damping constant and K is the stiffness matrix. Integration with regard to the movement of the equation (01) which represents the motion in terms of strength, gives us the equation of dynamic equilibrium in terms of energy given as follows:

$$\int_0^t [dx(t)]^T M\,\ddot{x}(t) + \int_0^t [dx(t)]^T C\dot{x}(t) + \int_0^t [dx(t)]^T Kx(t) = -\int_0^t [dx(t)]^T\, Mr\ddot{x}_g(t)$$

$$E_I(t) = E_K(t) + E_D(t) + E_S(t) + \; E_H(t) \qquad (2)$$

With :

$E_I(t)$ = input energy of seism.
$E_K(t)$ = kinetic energy.
$E_D(t)$ = energy dissipated by structural damping.
$E_S(t)$ = stored potential energy.
$E_H(t)$ = energy dissipated by the hysteretic behavior of the damping of the isolation system

3. BEHAVIOR OF THE ISOLATION SYSTEM LRB

The isolation system LRB 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 cylinder controls the lateral displacements of the structure and absorbs part of the seismic energy.
The plastic of the lead core confers to this device an important hysteretic behavior. This hysteretic behavior can be represented by the bilinear approximation illustrated on the figure 01.

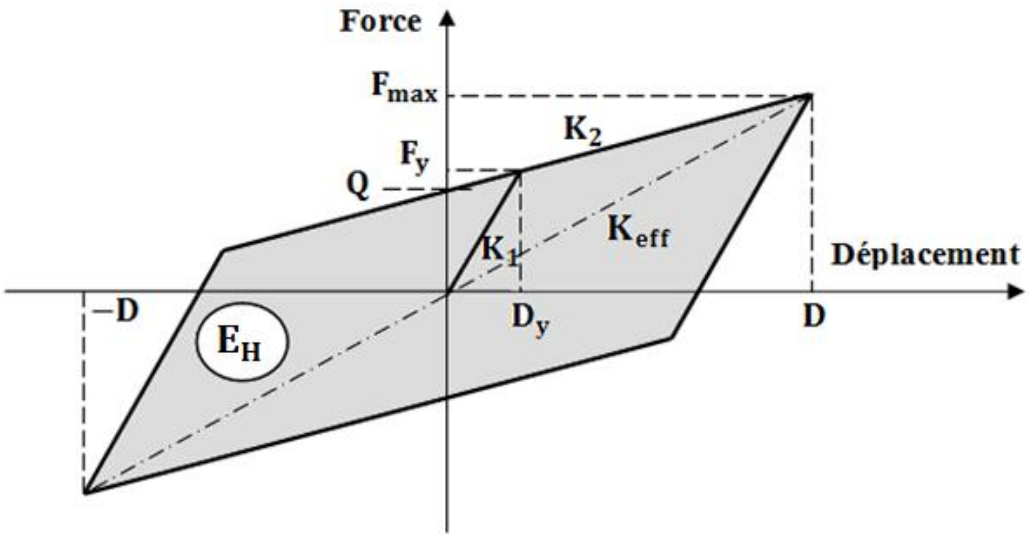


Figure 1. Bilinear approximation of a law of hysteretic behavior
Expressed in force-displacement

The parameters of the bilinear approximation expressing the law of hysteretic behavior are the following:

D_y: The yield displacement.

$$\text{With } D_y = Q/(K_1 - K_2) \tag{3}$$

D : The design displacement of lead rubber bearing LRB.

E_H: Energy dissipated by cycle corresponding to the design displacement, equal to the total area of hysteresis loop, it is given by the following formula :

$$E_H = 4Q(D - D_y) \tag{4}$$

F_y : The yield force in a monotonous loading.

Q : The force, corresponding to null displacement during a cyclic loading, represents also the characteristic strength and the yield force of lead bar for the LRB.

$$Q = F_y - K_2 D_y \tag{5}$$

F_{max} : The maximum shear force corresponding to the design displacement D.

K_1: Elastic stiffness for a monotonous loading, also equals to the stiffness of unloading in cyclic loading.

$$\text{With } K_1 = F_y/D_y \tag{6}$$

K_2: The post elastic stiffness.

$$\text{With } K_2 = (F_{max} - F_y)/(D - D_y) \tag{7}$$

K_{eff} : The effective stiffness of the LRB, it is given by the following formula:

$$K_{eff} = K_2 + \frac{Q}{D} \qquad D \geq D_y \tag{8}$$

β_{eff} : The effective damping factor of the seismic base isolation system, it is expressed as follows :

$$\beta_{eff} = \frac{4Q\,(D - D_y)}{2\pi\, K_{eff}\, D^2} \tag{9}$$

4. DESCRIPTION OF THE ISOLATED STRUCTURE AND THE SEISMIC EXCITATION

The structure used in the parametric study is an isolated building made of reinforced concrete that has rectangular form in plan 12 × 24 m² including four spans in the longitudinal direction and two spans in the transverse direction with a length of 6 m for each one. The height of a floor is of 3 m, the beams are of section 30×60 cm² and the columns are of section 50×50 cm² with full slabs of 18 cm of thickness, as it is represented in the figures 02 and 03.

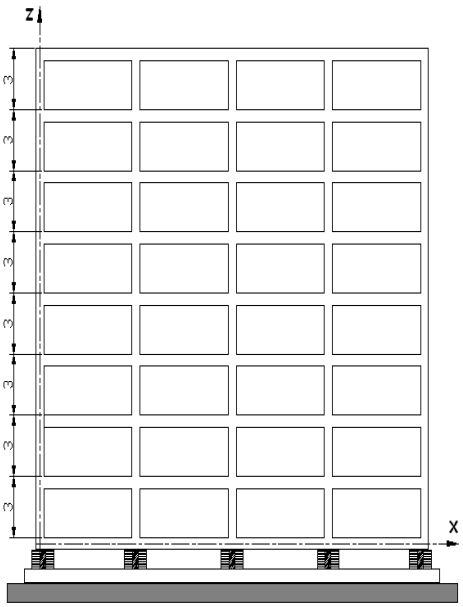


Figure 2. Section of the structure with base isolation system LRB.

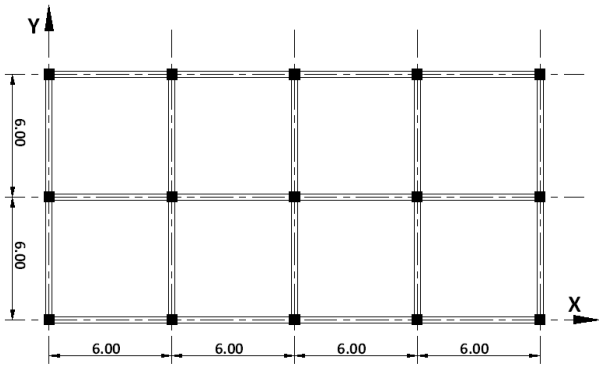


Figure 3. Plan of the structure.

To compare the influence of damping on the dynamic response of the isolated structures with the various percentages of effective damping and under various seismic excitations, an analysis of the responses by accelerograms is carried out and the considered seismic loadings are the following:

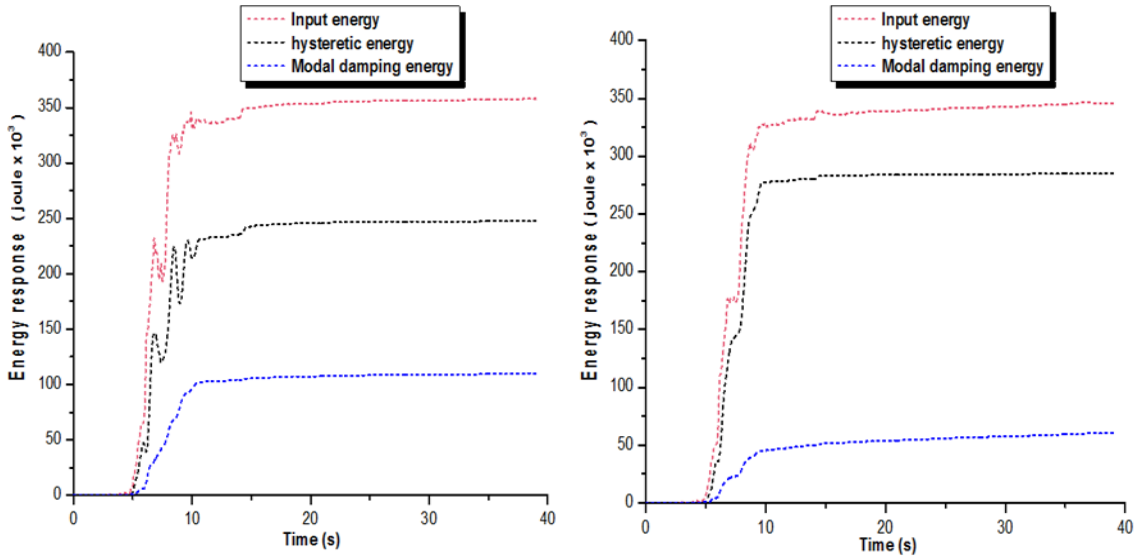
- The component of El Centro of the earthquake of Imperial Valley (1979).
- The component of Oakland Outer Harbor Wharf of the earthquake of Loma Prieta (1989).
- The component of Lexington Dam of the earthquake of Loma Prieta (1989).
- The component of Sylmar County of the earthquake of Northridge (1994).

With PGA (Peak Ground Acceleration) of 0.436 g, 0.287 g, 0.442 g and of 0.604 g respectively.

5. RESULTS AND DISCUSSION

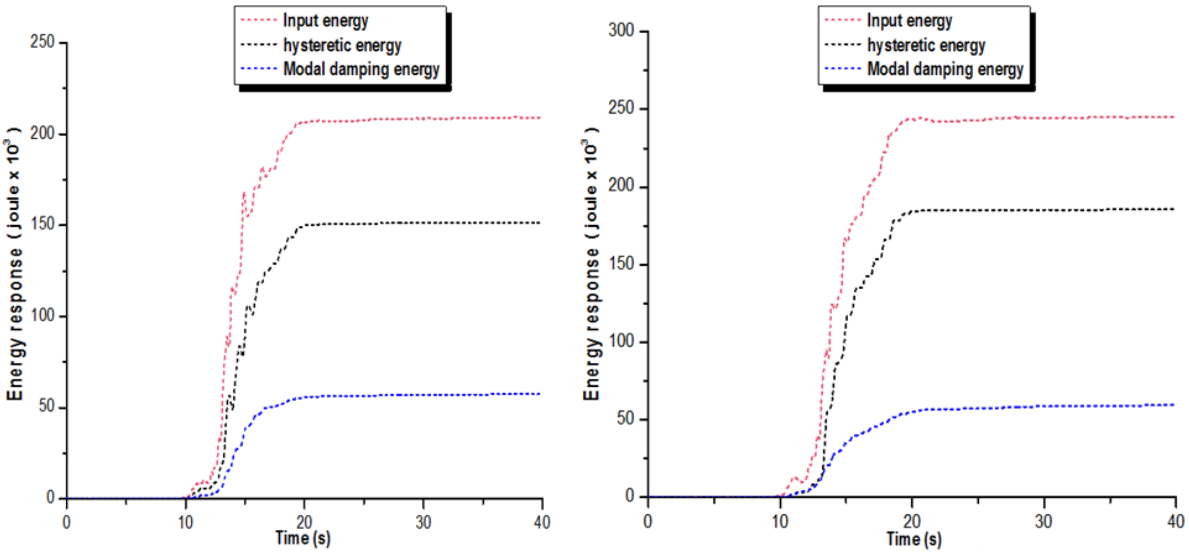
To illustrate the effect of the damping of the isolation system on the energy dissipation, a comparison was made between the input seismic energy (Input Energy), the energy absorbed by the isolation system (Hysteretic Energy) and modal damping energy (Modal damping energy) with two levels of low effective damping percentages (08%) and high (35%) for the four seismic loads used previously.

The results of this comparison are shown in figures below:



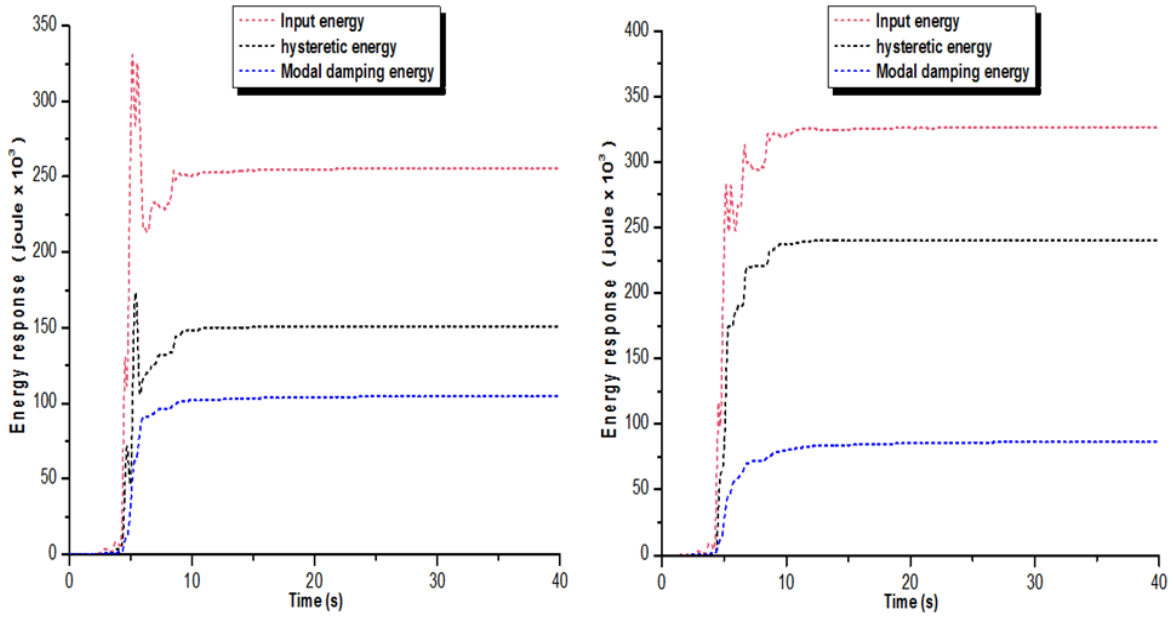
(a) Effective damping of 08 % (b) Effective damping of 35 %

Figure 4. Diagrams of energies absorbed by an isolated structure for low effective damping percentages (08%) and high (35%) subjected to the component of El Centro of Imperial Valley earthquake.



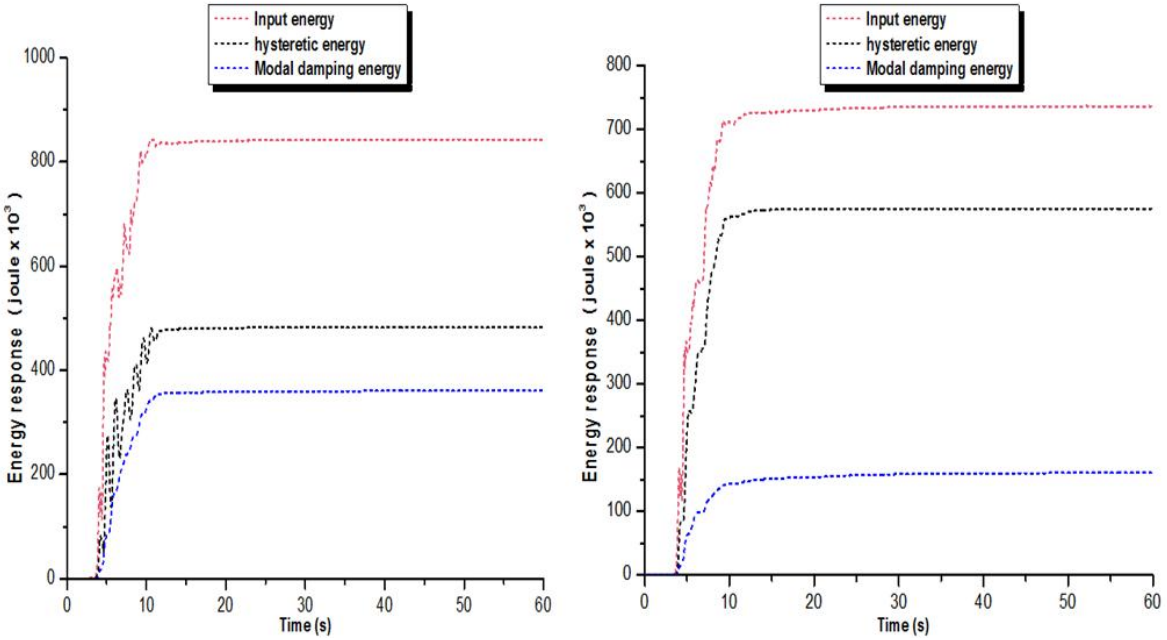
(a) Effective damping of 08 % (b) Effective damping of 35 %

Figure 5. Diagrams of energies absorbed by an isolated structure for low effective damping percentages (08%) and high (35%) subjected to the component of Oakland Outer of Loma Prieta earthquake.



(a) Effective damping of 08 % (b) Effective damping of 35 %

Figure 6. Diagrams of energies absorbed by an isolated structure for low effective damping percentages (08%) and high (35%) subjected to the component of Lexington Dam of Loma Prieta earthquake.



(a) Effective damping of 08 % (b) Effective damping of 35 %

Figure 7. Diagrams of energies absorbed by an isolated structure for low effective damping percentages (08%) and high (35%) subjected to the component of Sylmar County of Northridge earthquake.

Based on the comparison of the results between the figures 04 (a), 04 (b), 06 (a), 06 (b), 07 (a) and 07 (b), we find that the increasing of effective damping percentages reduces the input seismic energy and the energy of the modal damping and an increase in the energy absorbed by the isolation system for the components of seismic excitations (Imperial Valley, Lexington Dam Sylmar County). Therefore, the difference between the input seismic energy and that absorbed by the isolation system is reduced with the increase of the effective damping, which shows the influence of the damping for an isolation system in an isolated structure.
The figures 05 (a) and 05 (b) show that the input seismic energy, the energy of the modal damping and the energy absorbed by the isolation system are increased with the increasing of the effective damping for the component of Oakland Outer of Loma Prieta earthquake. Therefore, the difference between the input seismic energy and that absorbed by the isolation system remains almost invariable with the growth of the effective damping. This indicates that the damping of the seismic isolation system is more efficient to dissipate seismic energy induced in a medium or high seismic excitation and becomes less efficient for low excitations as shown by the accelerogram of the component of Oakland Outer having PGA of 0.287 g.

6. CONCLUSION

The results of the dynamic response of isolated structures in terms of absorbed energy obtained by the comparative study on the low and high effective damping of the seismic isolation system LRB allowed us to deduce that the increase of the effective damping percentages reduces the input seismic energy

and the energy of the modal damping and an increase of the energy absorbed by the isolation system. This explains the reduction of the difference between the input seismic energy and that absorbed by the isolation system in accordance with the increase of the effective damping.

REFERENCES

KAAB M. Z. and OUNIS A. (2011),"Influence of the damping of the seismic base isolation system LRB on the dynamic response of the isolated structures" INTERNATIONAL JOURNAL OF CIVIL AND STRUCTURAL ENGINEERING, Vol. 1, No 4, pp. 817-826.

Chenghao Wu, Yu Li, Haoyu Li, Kai Zhang (2008)," Parametric Study on Seismic Energy Response of Base-isolated Structures", International Workshop on Modeling, Simulation and Optimization, IEEE computer society, pp. 375-378.

Federal Emergency Federal Agency, FEMA 274 (1997)," Seismic Isolation and Energy Dissipation ", NEHRP COMMENTARY ON THE GUIDELINES FOR THE SEISMICREHABILITATION OF BUILDINGS, Chapter 09, Washington DC.

Naeim F., Kelly J. M. (1999)," Design of seismic isolated structures from theory to practice", John Wiley & Sons, New York.

Kelly J. M. (1997)," Earthquake-Resistant Design with Rubber ", Springer-Verlag, London.

Mayes R. L., Naeim F. (2001)," Design of Structures with Seismic Isolation", THE SEISMIC DESIGN HANDBOOK, 2nd edition, Chapter 14.

Yang Y.B.,Chang K.C. and Yau J.D. (2003)," Base Isolation " EARTHQUAKE ENGINEERING HANDBOOK, Chapter 17, CRC PRESS, Washington DC.

CSI, ETABS Nonlinear Version 9.0.0 (2003)," Integrated Software for Structural Analysis and Design", Computers and Structures, Inc, Berkeley, California, USA.

Ioannis P. (2007)," Le rôle de l'amortissement dans l'isolation sismique", 7ème Colloque National AFPS, Ecole Centrale Paris.