DOI: 10.2478/sspjce-2023-0004

The Use of Seismic Isolators to Improve Building Performance

Madi Rafik[1], Bordjiba Abdelhak[2*]

[1]Université 8 Mai 1945, Guelma, Algérie-
[2]Université Badji Mokhtar, Annaba, Algérie
*e-mail: bordjibaabdelhak@gmail.com

Abstract

The use of seismic isolators is a design method that involves inserting a flexible element at the base of the structure to decouple its movement from that of the ground to reduce vulnerability to earthquakes. They also make it possible to reduce the demand for force and deformation on the various structural elements. The aim of this research is to evaluate the contribution of HDRB high damping elastomeric seismic isolators in the reduction of seismic forces. It also consists in comparing the results of the dynamic analysis of the two fixed base structures in frames or frames braced by shear walls with the isolated structure mounted on an HDRB elastomer system and subjected to the same seismic excitation using the SAP 2000 calculation software. The results obtained showed an attenuation in the accelerations, a lengthening of the period, strong reduction in displacements and a reduction in the shearing force at the base of the isolated structure compared to fixed base structures.

Keywords: building, seismic, energy dissipation, modelization, dynamic analysis

1 Introduction

The conventional approach to protecting buildings against earthquakes is to increase resistance and or ductility by reinforcing the structure or repairing damaged elements, in order to withstand significant loads by developing plastic hinges at well-determined places to dissipate energy by inelastic deformations. This approach is not entirely effective because of the amplification of the seismic solicitations transmitted to the buildings. The reduction of seismic forces is the most effective approach because it aims to partially shield the structure from the seismic action rather than reinforce it so that it can withstand high loads. To this end, the use of seismic protection and isolation systems makes it possible to decouple the structure from ground movements induced by an earthquake in order to prevent the occurrence of damage. The insulation at the base consists in putting between the foundation and the superstructure seismic isolators which absorb the seismic energy due to their nonlinear responses and they have a very important horizontal deformability to be able to dissipate the deformation transmitted to the construction and a very high vertical rigidity to support the weight of the structure. It also makes it possible to increase the fundamental period (Figure 1) and reduce the vibration frequency of the structure in order to avoid the phenomenon of resonance [1]. Many variables may have different effects

on the performance of the buildings particularly the ones with irregularities such as torsion. Force-based method (FBD) and displacement-based method (DBD) have been commonly used to evaluate the performance of the structures. The DBD method may give more realistic prediction of damage levels where this method directly provides plastic hinge deformations for the target displacement. Through combining this method to the capacity design principles, nonductile formations can be avoided and more economical outcomes can be achieved [12]. With seismic insulators, a potentially high level of protection of buildings compared to conventional techniques can be achieved with in addition, the realization of savings on project costs [2]. The insulation technique is not reserved for new structures; on the contrary, one of its main advantages is that it can be applied very well to the seismic rehabilitation of existing constructions [3].

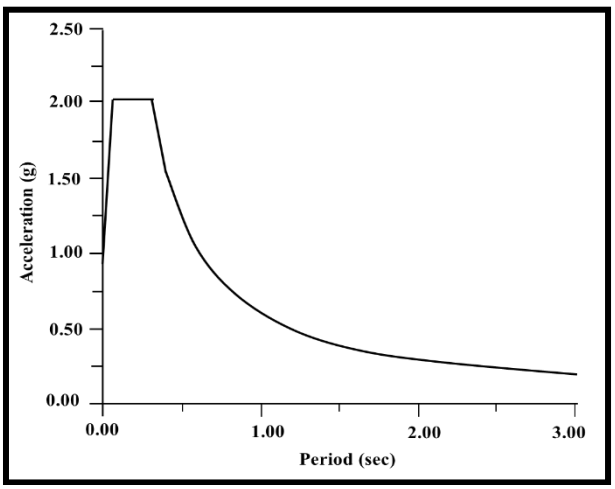


Figure 1: UBC 97 design spectrum [3]

2 Behavior of Seismic Isolators

Seismic isolation is about providing a discontinuity between the foundation and the superstructure, so that the seismic energy cannot be fully transmitted to the superstructure. It induces a significant reduction in the acceleration of the upper floors and inter-floor movements. Therefore, it ensures the protection of the structure. According to their mode of operation, seismic supports can be classified into several categories [4]:

- Deformation supports: in lead low damping rubber bearing (LDRB), lead rubber bearing (LRB) and in high damping rubber bearing (HDRB).
- Deformation and sliding supports.
- Bearing supports.

2.1 Deformation Supports

They are made of hooped elastomer: alternating layers of elastomer, natural rubber, or synthetic elastomer and of hoops in the form of metal plates.

The horizontal deformability is ensured by the elastomer layers and the vertical rigidity of the supports is ensured by the presence of the hoops. They allow horizontal flexibility and greatly reduce the relative displacement of floors.
In case of the more flexible of elastomers, a lower seismic load felt by the building. But too much flexibility of the supports considerably reduces the stability of the structure in normal times [5].
We distinguish:

- Support in lead low damping rubber bearing (LDRB): these isolators consist of two thick steel end plates and many thick steel shims. The behavior of the material in shear is completely linear up to shear stresses greater than 100%, with damping of around 2% to 3% of critical damping [6].
- Support in lead rubber bearing (LRB): the elastomer base isolator with lead bar is rather flexible in the horizontal direction, but quite rigid in the vertical direction (Figure 2). It prolongs the period of the structure and allows energy dissipation**.** The normal recommended period for optimal performance is between 1.5 and 2.5 sec [7].
- Support in high damping rubber bearing (HDRB): In this type supports, the elastomer used provides a significant amount of damping, usually from 8% to 15% of critical damping. It is vertically rigid, capable of supporting vertical gravity loads while being laterally flexible and capable of allowing large horizontal displacements (Figure 3).

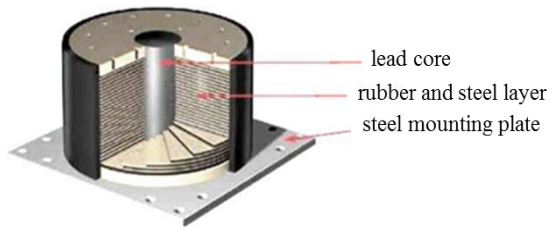


Figure 2: Lead rubber bearing isolator (LRB) [6]

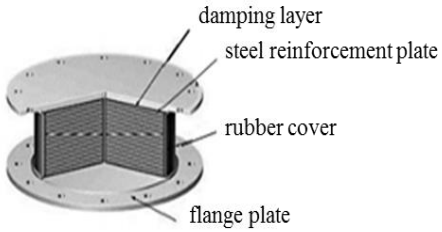


Figure 3: High damping rubber bearing isolator (HDRB) [6]

2.2 Sliding Supports

These are two separate blocks that slide relative to each other and allow the decoupling of the movements of the superstructure from those of the foundation elements by means of a sliding interface which dissipates seismic energy by friction (Figure 4). They can be used with both light and massive structures, because their period depends only on the radius of curvature. They can also support a high vertical load and provide more than 30% damping [8]. Slip-based isolator systems are frequently applied in constructions and walkways because of its advantages, listed below, compared to conventional rubber bearings:

- The non-influence of the input frequency on this system.
- The torsional effects produced by asymmetric construction are reduced due to the coincidence of the center of mass of the structure and that of the sliding supports.

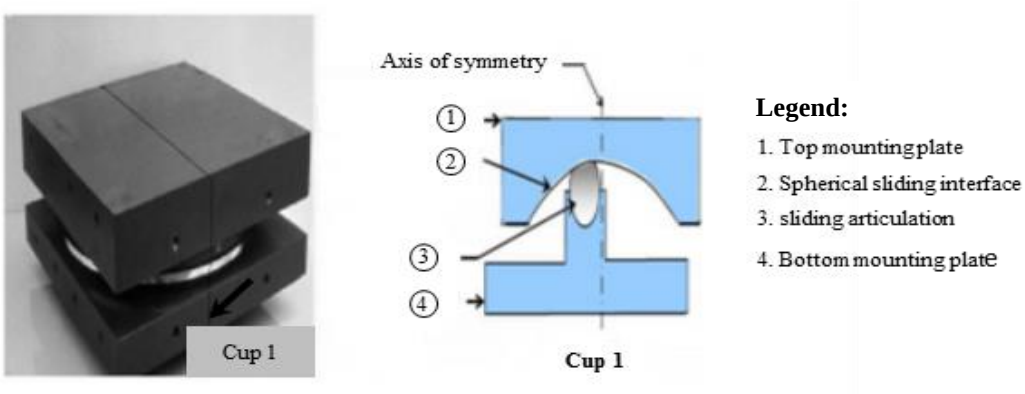


Figure 4: Sliding support [8]

2.3 Deformation and Sliding Supports

It is formed by the association of sliding plates and deformation supports. This system leads to a reduction in both acceleration and displacement of the Superstructure and thus leads to a significant decrease in shear forces at the base. This is particularly advantageous in the case of constructions on deep foundations, more sensitive to shear than superficial foundations.

2.4 Rolling Supports

To allow movement in two directions, spherical balls or two orthogonal layers of cylindrical rollers are used. The main disadvantages of this system are the seizure after a prolonged period without solicitation and their low damping (Figure 5).

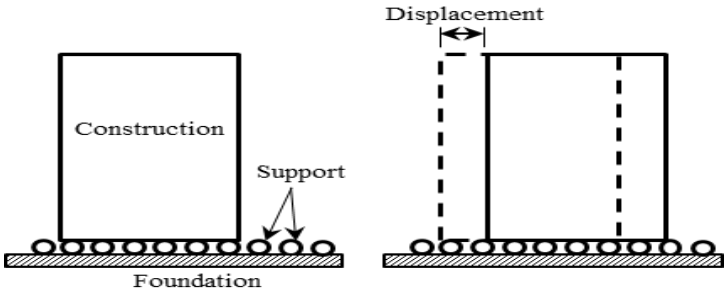


Figure 5: Rolling supports

3 Modeling of Seismic Isolator Based on Elastomer

Fretted elastomers have the ability to both increase the natural period of the structure and dissipate energy so as to limit displacement. These devices can withstand very high shear strains.

The various parameters which characterize the behavior law of the isolator are (Figure 6): elastic rigidity K_e, horizontal elastoplastic rigidity K_d, the effective stiffness at maximum displacement K_{eff}, plasticization resistance Q_d, plasticizing displacement D_y and design displacement D_u.

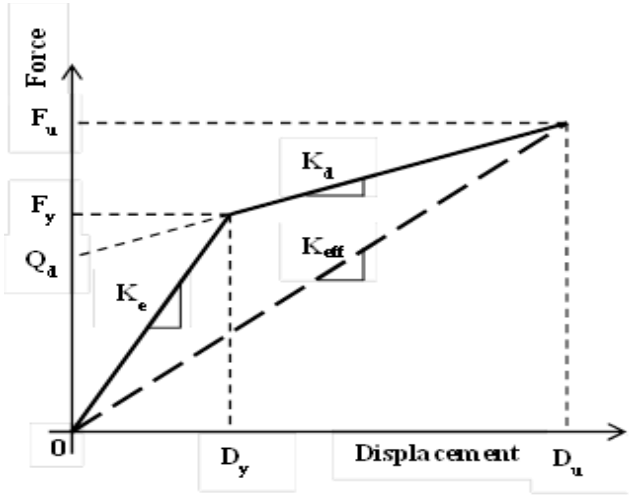


Figure 6: LRB behavior law [9]

The seismic isolators will be modeled in the SAP2000 software, using "Link Element" with hysteretic behavior of an elastomeric isolator. The bidirectional hysteritic model adopted with a bilinear behavior coupled in shear (Figure 7) is based on the model of Wen [9].

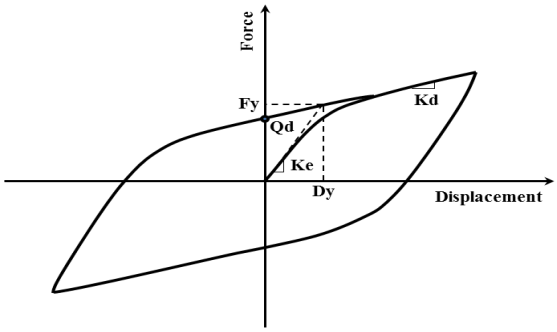


Figure 7: Hysteretic behavior of an elastomeric isolator [9]

4 Presentation of the Structure

It is a reinforced concrete structure (ground floor + 5 floors). The floor of the various stages is hollow body of 20 cm thick. The dimensions are (30x35) cm for the beams, (30x30) for chaining and (30x40) for columns. The floor height is 3.15 m. The structure is located in a class IIa seismic zone. The foundation soil is of the loose type. The characteristics of the materials are as follows:

- Concrete: F_C28 = 25 MPa, E_C = 32164 MPa.
- Steels: FeE400 for longitudinal reinforcement: E_S = 2.105 MPa, f_Y = 400 MPa
  FeE235 for transverse reinforcement: E_S = 2.105 MPa, f_Y = 235 MPa.
- Permanent loads G and overloads Q are as follows:
  $G_{TERRACE}$ = 0.57 tf/m², $Q_{TERRACE}$ = 0.10 tf/m², G_{FLOOR} = 0.50 tf/m², Q_{FLOOR} = 0.10 tf/m².

Structure 1 is in autostable frame with fixed supports (Figure 8). Structure 2 is made of autostable frame braced by shear walls of 15 cm thick, with fixed supports (Figure 9). Structure 3 (Figure 8) is made of autostable frame on isolated supports (seismic isolators).

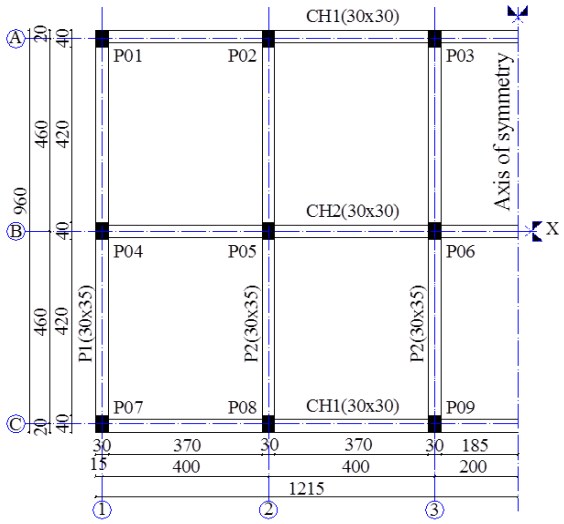


Figure 8: Formwork floor, structure 1 and 3

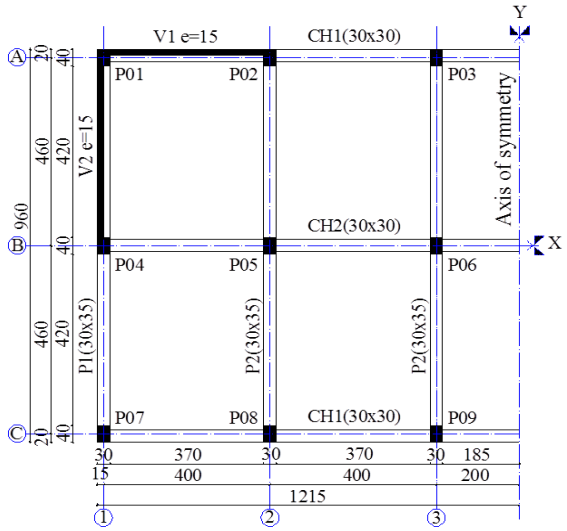


Figure 9: Formwork floor, structure 2

5 Sizing of the Isolator

The Algerian Code RPA 99, version 2003, provides no guidance on the calculation of structures on seismic supports. For this reason, we will use the code UBC 97 [10]. The characteristics of the chosen isolator HDRB (Figure 10), are the following: Elasticity modulus E = 1800 kN/m^2, Shear modulus G = 540 kN/m^2, maximum shear stress γ_{max} = 150%.
According to UBC 97, the seismic data is:

seismic zone factor (2a)	z = 0.15
zone seismic coefficients	C_A = 0.3 and C_V = 0.5
maximum capable earthquake response coefficient	M_M = 2
amortization β_{eff} = 15%	B_D = 1.35 and B_M = 1.35
periods : T_D	2 sec and T_M = 2.5 sec.
soil profile type S_E	C_{VM} = 0.50 and $_{VD}$ = 0.50
type of fault A, proximity to the fault 10 km	N_v = 1.2 and N_a = 1

The sizing steps are as follows:

A. Calculation of the values of the minimum and maximum total rigidities K_D and K_M.
The periods T_D and T_M, are defined by:

$$T_D = 2\pi\sqrt{\frac{W}{K_D}} \quad \text{and} \quad T_M = 2\pi\sqrt{\frac{W}{K_M}} \tag{1}$$

This gives:

$$K_D = \frac{4\pi^2 W}{T_D^2 g} \quad \text{and} \quad K_M = \frac{4\pi^2 W}{T_M^2 g} \tag{2}$$

with W = 12500 kN, we find:
K_D = 12563.20 kN/m and K_M = 8040.45 kN/m.
This gives for each of the 18 shock absorbers:
$K_{D/absorber}$ = 697.95 kN/m and $K_{M/absorber}$ = 446.69 kN/m.

B. Design displacement calculations D_U and maximum D_M

$$D_U = \frac{\left(\frac{g}{4\pi^2}\right) C_{VD}\, T_D}{B_D} \quad \text{and} \quad D_M = \frac{\left(\frac{g}{4\pi^2}\right) C_{VM}\, T_D}{B_M} \tag{3}$$

Which gives: D_U = 0.18 m and D_M = 0.23 m

C. Calculation of rubber thickness t_r

$$t_r = \frac{D_U}{\gamma_{\max}} = 0.12 m$$

we take t_r = 0.15 m

D. Calculation of the support section A

Horizontal rigidity K_H of a shock absorber is given by: $K_H = \frac{G A}{t_r}$

Taking $K_H = K_{D/asorber}$, we find: $A = \frac{K_H t_r}{G} = 0.19 m^2$

for a circular isolator: $A = \pi D^2/4$ = 0.19 m^2 Which gives D = 0.50 m.

E. Calculation of the rubber thickness between two steel frets t_c

The form factor S is given by: $S = \frac{D}{4 t_c}$

either: $t_c = \frac{D}{4 s}$

The form factor varies between 5 and 30. We take S = 10.
Which gives t_c = 12.50 mm. We take t_c = 12 mm.

F. Calculation of the number of steel frets n_a

$n_a = \frac{t_r}{t_c} - 1$, either 11 steel frets 2 mm thick.

G. Calculation of the total height H of the isolator

H = 12x12+11x2+2x25 = 216 mm

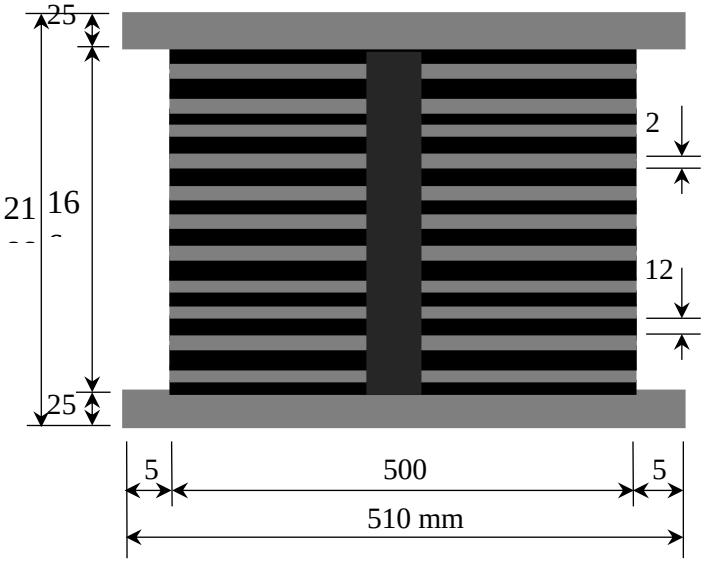


Figure 10: HDRB Isolator characteristics

5.1 Description of the Seismic Excitation

The two horizontal components of accelerograms used in the analysis are (N-S) and (E-W). They are applied respectively in the transverse and the longitudinal direction of each structure. The accelerograms of these two components are shown in Figures: 11 and 12. A_{max} = 0.134 g at t = 0.695 sec.

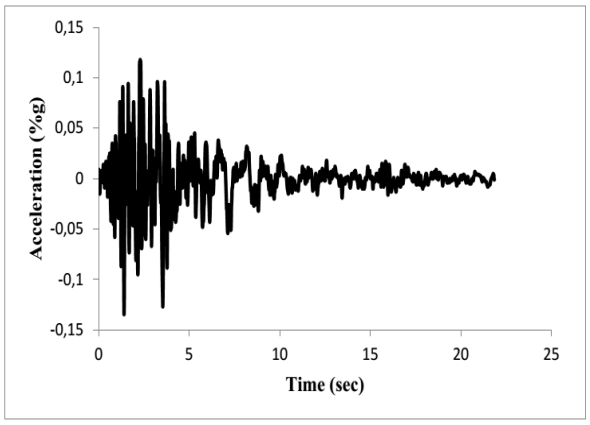


Figure 11: Transverse component [11]

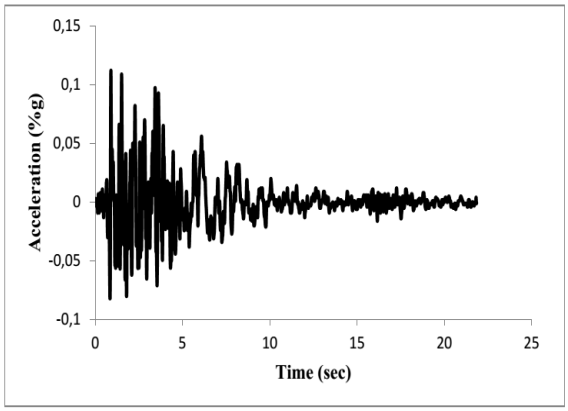


Figure 12: Longitudinal component [11]

The modeling of the different structures is mentioned in Figure 13.

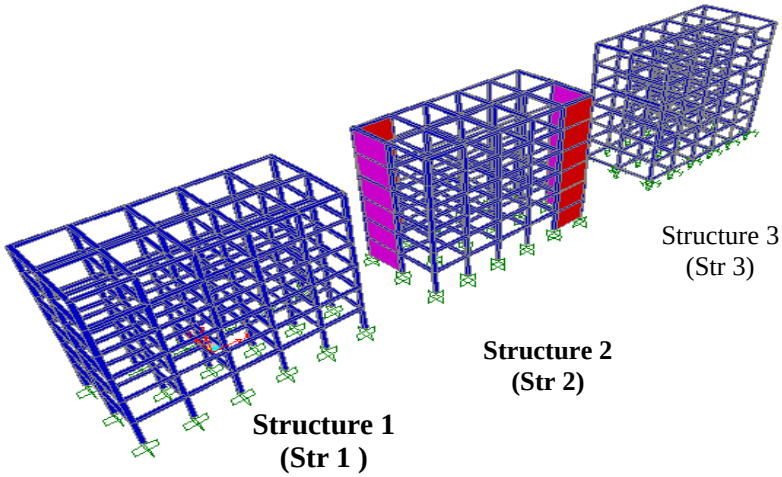


Figure 13: Modeling of the structures by SAP2000, V14

6 Results Analysis

The periods obtained for each type of structure are given in Table 1.

Table 1: Comparison of periods

Mode	Period (sec)		
	Fixed base structure (Frame)	**Fixed base structure (Frame + Shear wall)**	**Isolated Structure**
1	1.32	0.51	2.71
2	1.21	0.33	1.86
3	0.43	0.21	1.39
4	0.38	0.11	0.72
5	0.24	0.09	0.51
6	0.21	0.08	0.48
7	0.15	0.06	0.42
8	0.12	0.05	0.39
9	0.08	0.05	0.43
10	0.07	0.04	0.32
11	0.06	0.03	0.30
12	0.06	0.02	0.25

These results show an increase in the period of the isolated structure compared to fixed base structures. The maximum displacements and accelerations obtained for each type of structure are given in Table 2.

Table 2: Comparison of displacements and acceleration

Level	Maximum displacement (cm)			Maximum acceleration (m/s^2)		
	Str 1	**Str 2**	**Str 3**	**Str 1**	**Str 2**	**Str3**
6	4.43	0.45	5.5	1.95	2.54	0.95
5	4.18	0.38	4.9	1.65	1.99	1.06

4	3.71	0.30	4.2	2.03	1.77	1.26
3	2.97	0.21	3.4	1.83	1.80	1.36
2	1.97	0.12	2.4	1.85	1.84	1.25
1	0.80	0.05	1.4	1.51	1.37	0.91
0	0.00	0.00	0.5	0.00	0.00	0.46

One notices an increase in displacements and a reduction of accelerations in the various levels of the structure isolated compared to the fixed base structures.
The inter-story displacements obtained for each type of structure are mentioned in Table 3.

Table 3: Inter-story displacements

Niv.	**Inter-story displacements (cm)**		
	Str 1	**Str 2**	**Str 3**
6	0.25	0.07	0.60
5	0.47	0.08	0.70
4	0.74	0.09	0.80
3	1.00	0.09	1.00
2	1.17	0.07	1.00
1	0.80	0.05	0.90

One notices an increase in the inter-story displacements of the isolated structure compared to the fixed base structures. The shear forces at the base for each type of structure are given in Table 4.

Table 4: Comparison of shear forces at the base

Sens	**Shear force at the base (t_f)**		
	Str 1	**Str 2**	**Str 3**
Transversal	180.51	273.66	31.86

According to the results obtained, the insulation system reduces the shearing forces at the base.

7 Conclusion

During an earthquake, the majority of victims are due to the collapse of buildings on their occupants. The best response to this risk is to build structures that comply with earthquake-resistant codes, the objective of which is to use design techniques that make it possible to create resistant structures. It is about saving as many human lives as possible by avoiding the collapse of structures. The seismic isolator is one of the techniques used to reduce the dynamic effect of vibration. For this research we used an isolator type elastomer with high damping HDRB. After pre-dimensioning of the seismic isolator according to code UBC97, and the dynamic study by SAP2000, a comparison was made between the different calculation results. The results of the dynamic study show: an increase in the period and displacements, attenuation in acceleration, a reduction in the shearing force at the base of the isolated structure compared to fixed base structures. The isolated structure moved like a rigid body because the displacements are located mainly at the levels of the supports. Therefore, the insulation of structures increases the performance of buildings by reducing the dynamic response. It is more efficient to minimize structural damage and save lives during and immediately after an earthquake. We conclude that the seismic isolator technique is an accepted design alternative for reducing seismic risks and

improving the performance of structures. In the future, it aims to study the seismic performance of an existing high-rise building exhibiting torsional irregularity. This building rests on lead rubber bearings designed taking into account the force in the shear walls whose main objective is to improve the seismic performance of the building by eliminating the harmful torsional effects and decreasing the seismic forces.

References

[1] Abdollahzadeh, G., & Sadeghi, A, (2018). Earthquake recurrence effect on the response reduction factor of steel moment frame. Asian journal of Civil Engineering, 19, 993–1008.

[2] Faroughi, A., Moghadam, A. S., & Hosseini, M, (2017). Seismic progressive collapse of MRF–EBF dual steel systems. *Proceedings of the Institution of Civil Engineers Structures and Buildings*, *170*, 67–75.

[3] Hakim, R. A., Alama, M. S., & Ashour, S. A, (2014). Seismic assessment of RC building according to ATC-40, FEMA-356 and FEMA-440. *Arabian Journal for Science and Engineering, 39*, 7691–7699.

[4] Hosseini, M., Fanaie, N., & Yousefi, A. M. (2014). Studying the vulnerability of steel moment resistant frames subjected to progressive collapse. *Indian Journal of Science and Technology, 7*(3), 335–342.

[5] Kiakojouri, F., & Sheidaii, M. (2018). Effects of finite element modeling and analysis techniques on response of steel moment-resisting frame in dynamic column removal scenarios. *Asian Journal of Civil Engineering, 19*, 295–307.

[6] Kordbagh, B., & Mohammadi, M. (2017). Influence of seismicity level and height of the building on progressive collapse resistance of steel frames. *The Structural Design of Tall and Special Buildings, 26*(2), e1305.

[7] Manasa M. S., Mathai A., 2017. Performance of Lead Rubber Bearing as a Base Isolator. *International Journal of Science Technology & Engineering* 3(1).

[8] Mazloom, M., Gholipour, M., & Ghasemi, M. (2019). Evaluating inelastic performance of mega-scale bracing systems in low- and medium-rise structures. *Asian Journal of Civil Engineering, 20*, 383–393.

[9] Salmasi, A. C., & Sheidaii, M. R. (2017). Assessment of eccentrically braced frames strength against progressive collapse. *International Journal of Steel Structures, 17*(2), 543–551.

[10] Vara Lakshmi, T. V. S., & Adiseshu, S. (2016). A study on preparing of high performance concrete using silica fume and fly ash. *The International Journal of Engineering and Science, 5*, 29–35

[11] Xu, J.-G., Wu, G., & Feng, (2019). D.-CNear fault ground motion effects on seismic resilience of frame structures damaged in wenchuan earthquake. *Structure and Infrastructure Engineering, 16*, 1347–1363.

[12] Saritas, F. (2022). Seismic Performance Assessment of an Isolated Multispan Bridge. *Arab. J. Sci. Eng., 47*, 12993–13008.