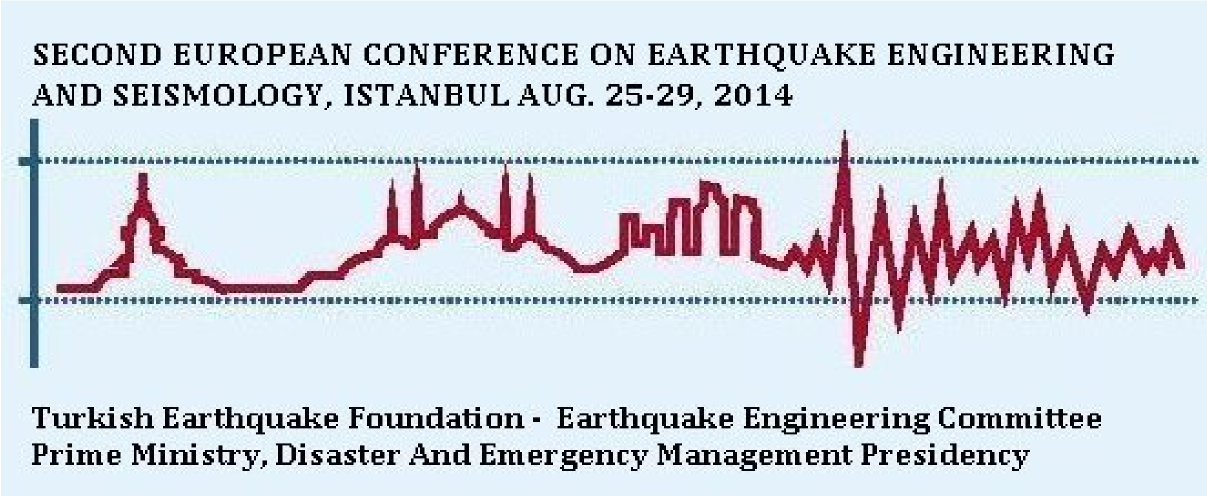

SEISMIC ISOLATION OF REINFORCED CONCRETE STRUCTURES «NONLINEAR DYNAMIC METHOD»

Naima ADJOU [1] and Naima HADDADOU [2]

ABSTRACT

Seismic isolation is a relatively young technology compared to conventional methods of prevention against earthquakes, its appearance goes back to the Early 20th century, its principle is quite simple, it consists in creating a discontinuity between the foundation and the superstructure, so that the seismic energy cannot be completely transmitted in the structure. The objective of this article is to show the effect of introducing seismic isolator in reinforced concrete structures built-in zone of medium and high seismicity within the framework of Algerian earthquake resistant regulations « RPA99/version 2003». Therefore, the article includes numerical applications of nonlinear dynamic method on isolated structures.

Keywords: damping, energy dissipation, isolator, nonlinear dynamic method, seismic isolation.

INTRODUCTION

In Algeria, the organization of technical control of construction was the first to introduce the seismic isolation technique of structures through the construction of seat of its agency in Ain Defla, located in an area of high seismicity. The project of the Great Mosque of Algiers, which is under construction, will be built using this technique. The conventional earthquake resistant designs rely on the strength and ductility of structural elements to resist to seismic induced forces and to dissipate the seismic energy, which prevents the collapse of structures in case of earthquake. In contrast, the approach of the base isolation reduces damage due to horizontal seismic forces transmitted to the structure [3]. The objective of this paper is to evaluate the seismic response of eight base isolated reinforced concrete structures with lead rubber bearing system, using the nonlinear dynamic method. The analyzed structures are located in areas of high seismicity and sized according to the Algerian seismic regulations RPA99 [1]. At the end a comparison of the results has been made in terms of inter-storey displacement and base shear.

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THE SEISMIC ISOLATION

The principle of seismic isolation is quite simple; it consists to create a discontinuity between the foundation and the superstructure, so that seismic energy cannot be entirely transmitted into the structure. There are two categories of isolation systems extensively used. The first category includes the family of elastomeric bearings, in which we find the High Damping Rubber Bearing system, the Lead Rubber Bearing system LRB and other systems. The second category includes the family of sliding bearings, in which we find the friction pendulum system, FPS, and sliding bearing System without re-centering SI. All seismic isolation systems must meet the following three requirements [4]:

- Sufficient horizontal flexibility to increase the structure period and spectral demand, except for very soft soil sites;
- Sufficient energy dissipation capacity to restrict the displacements of seismic isolators;
- Adequate rigidity for the isolated structure is identical to the fixed base structure under the service loads.

DESCRIPTION OF THE STUDIED STRUCTURES:

Eight isolated base structures are the subject of this study; the structures are reinforced concrete portal frames. They have a square shape, regular in plan and elevation. The height of a level is 3 m and the number of levels is 3 to 10. The plan dimensions are (16mx16m) Figure 1.

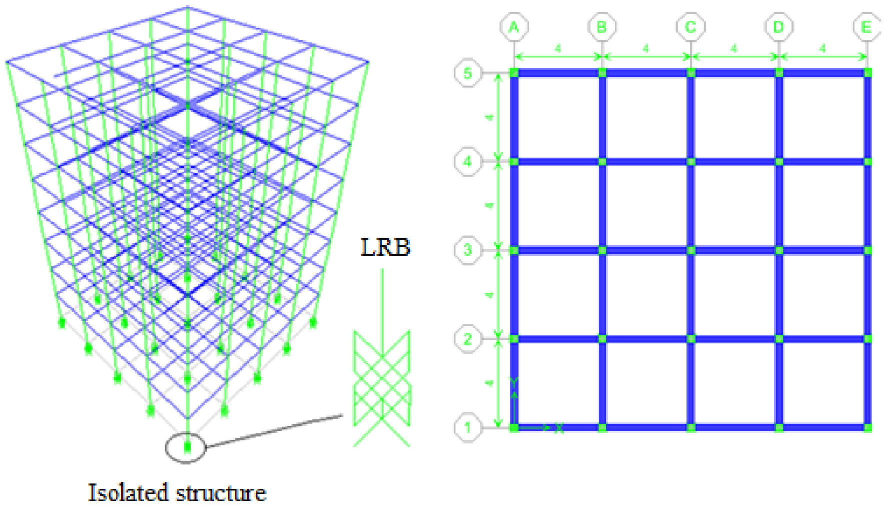

Figure 1. Graphical representation of the studied structures.

The mechanical characteristics of the materials are:
The compressive strength of concrete at 28 days is 25MPa.
The Modulus of elasticity of concrete is 3.21 107 KN/m².
Longitudinal and transverse reinforcement steel Fe E400.
The loads G and the overloads Q are:
Terrace: G=6.75 KN/m² and Q=1.00 KN/m².
Floor: G=4.20 KN/m² and Q=1.50KN/m².
The isolation system used in this analysis is the lead rubber bearings system LRB, 25 bearings, the laws of behavior bearings LRB is shown in Figure 2.

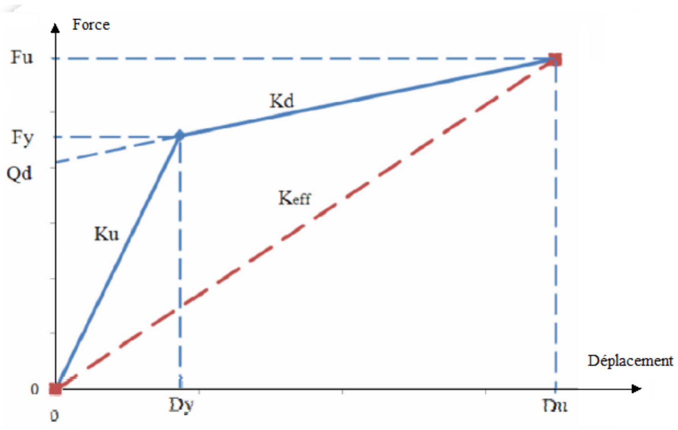

Figure 2. Law behavior bearing

The formulas used to calculate the laws of behavior bearings are as follows:

$$Ku = \alpha\, Kd \tag{1}$$

$$K_d = K_{eff} - \frac{Q_d}{D} \tag{2}$$

With:
Ku: Linear Stiffness
Kd: Nonlinear stiffness
Keff: Effective stiffness
D: Displacement design
Qd: Force elastic

$$Q_d = \frac{\pi}{2}\, Keff\ \beta eff\ \ D \tag{3}$$

$$D_y = \frac{Q_d}{K_u - K_d} \tag{4}$$

$$F_y = K_u\ D_y \tag{6}$$

The dimensions adopted (diameter, height) and the laws of nonlinear behavior of the seismic bearings LRB for the eight structures studied are summarized in Table 1.

Table 1. Dimensions and laws of behavior of LRB

	LRB (Lead Rubber Bearing)			
Levels	Diameter D (cm)	Height H (cm)	Horizontal effective stiffness K_{eff} [KN/m]	Vertical stiffness K_v [KN/m]
3	38.00	18.00	2547.33	2096720.79
4	40.00	23.00	1963.55	1597224.97
5	44.00	28.00	1688.23	1546113.78
6	44.00	34.00	1431.21	1344446.76
7	44.00	37.00	1287.55	1022223.98
8	46.00	42.00	1138.58	881227.57
9	46.00	52.00	1048.51	828677.90
10	50.00	55.00	950.45	998265.61

NONLINEAR DYNAMIC ANALYSIS

The dynamic analysis of temporal responses (accelerograms) is used in this study. This method is the most accurate to analyze the nonlinear behavior of the isolation system and to study the responses of the structures in function of time. The program used for the nonlinear dynamic analysis is program ETABS V9 [2]. The accelerogram used in the analysis are those of the earthquake of Boumerdes 21 May 2003 registered at station of Dar El Beida, Keddara and Tizi Ouzou. In addition to the accelerogram of Northridge1994 (Sylmar station), El-Centro 1940, El Centro 1979, Loma Prieta 1989 (Hollister station) and Northridge 1994 (Newhall station). The characteristics of these accelerograms are summarized in Table 2

Table 2. The characteristics of accelerograms used in the dynamic analysis

Accelerograms	PGA (g)	PGV (cm/s)	PGD (cm)
Boumerdes 2003 (Dar El Beida station)	0.55	41.9	18.3
Boumerdes 2003 (Kaddara station)	0.34	18.9	4.6
Boumerdes 2003 (Tizi Ouzou station)	0.20	9.0	2.0
Northridge 1994 (Sylmar station)	0.84	128.88	32.55
El-Centro 1940 (N/S)	0.32	36.14	21.34
El-Centro 1979	0.436	108.71	55.16
Loma prieta 1989 (Hollister station)	0.37	62.779	30.18
Northridge 1994 (Newhall station)	0.59	94.72	30.47

The accelerograms used in this study are illustrated in figure 3

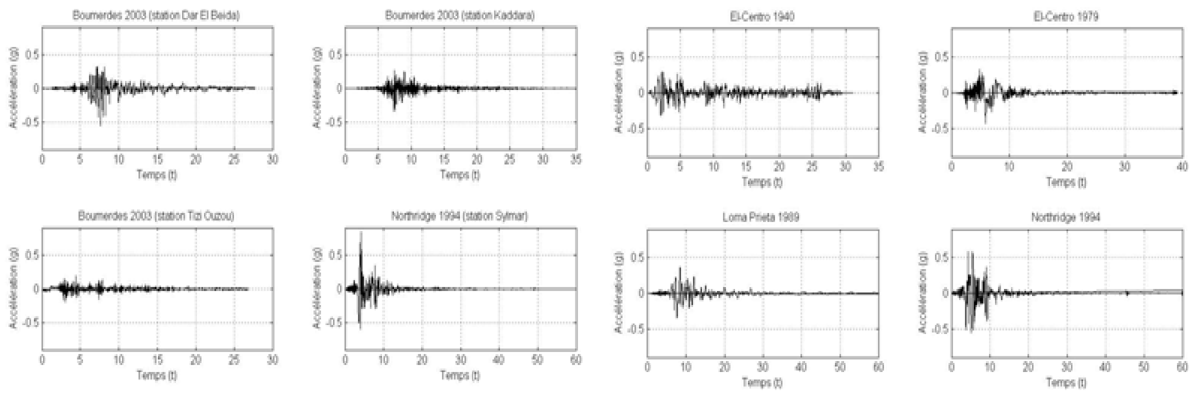

Figure 3. The accelerograms used in the dynamic analysis

The frequency content of the accelerograms used are shown in figure 4

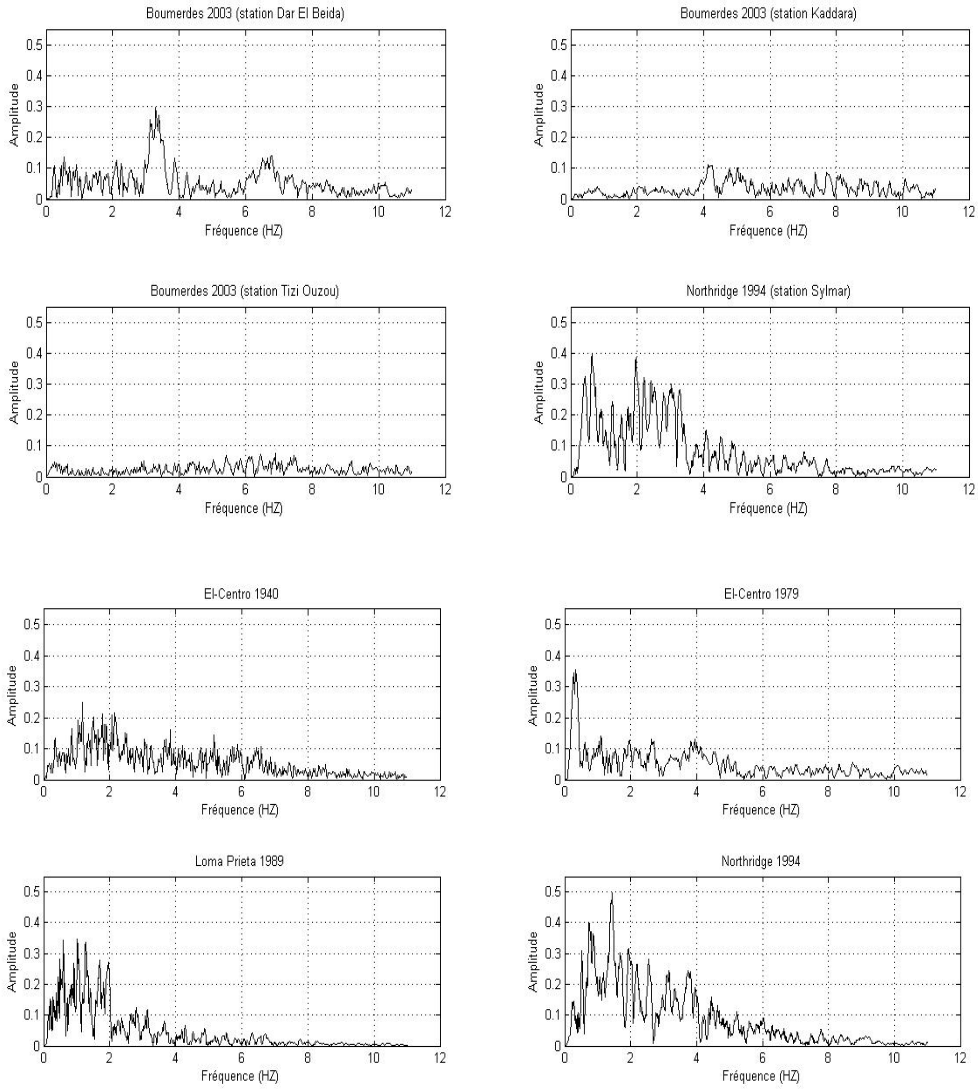

Figure 4. The frequency content of the accelerograms used

RESULTS

NATURAL PERIODS OF ISOLATED STRUCTURES

The results obtained for the structures are summarized in Table 3

Table 3. Les périodes propres des structures.

Levels	1	2	3	4	5	6	7	8
Period	0.504	1.013	1.198	1.402	1.593	1.865	1.981	2.202
Frequency	1.984	0.987	0.835	0.713	0.628	0.536	0.505	0.454

THE MAXIMUM DISPLACEMENTS OF LRB BEARINGS

The maximum displacements of the LRB bearings for the eight structures of 3 to 10 levels under the effect of earthquakes are summarized in Table 4 and shown in Figure 5

Table 4. The maximum displacements of LRB

Structure of N levels	Maximum displacement of LRB (m)							
	ELECENTO 1979	DARELBEIDA 2003	ELECENTO 1940	HOLLISTER 1989	KEDDARA 2003	NEWHAL 1994	SYLMAR 1994	TIZIOUZOU 2003
10	0.0014	0.0041	0.0919	0.007	0.0008	0.0233	0.0063	0.0014
9	0.0065	0.005	0.0757	0.0055	0.0007	0.018	0.0038	0.0013
8	0.0064	0.0035	0.0686	0.0052	0.0007	0.0134	0.0029	0.0009
7	0.0051	0.0029	0.0566	0.0044	0.0007	0.0101	0.0034	0.0009
6	0.0059	0.0021	0.0551	0.0034	0.0005	0.0085	0.0043	0.0009
5	0.0037	0.0018	0.0455	0.0025	0.0005	0.0063	0.0049	0.0007
4	0.0055	0.0013	0.05	0.0028	0.0006	0.0052	0.0032	0.0006
3	0.0071	0.0008	0.0249	0.0026	0.0002	0.0039	0.0045	0.0004

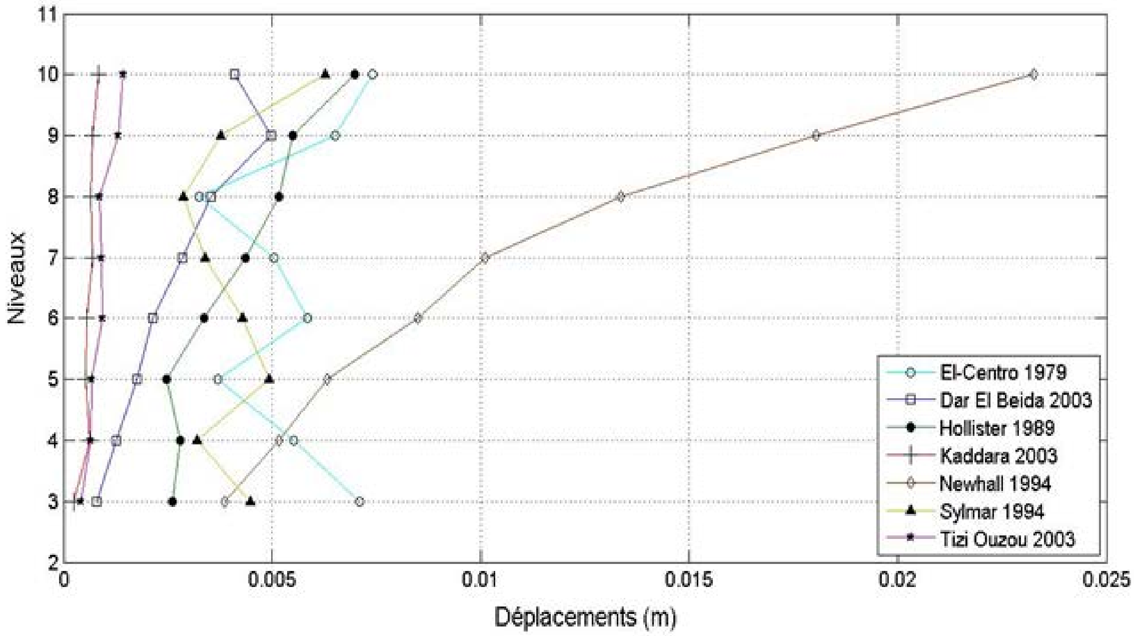

Figure 5. The maximum displacements of LRB

COMPARISON OF ABSORBED ENERGY

Figure 6 shows a comparison between the absorbed energy by the isolation system in the structures of 4, 7 and 10 levels, under the effect of eight earthquakes.

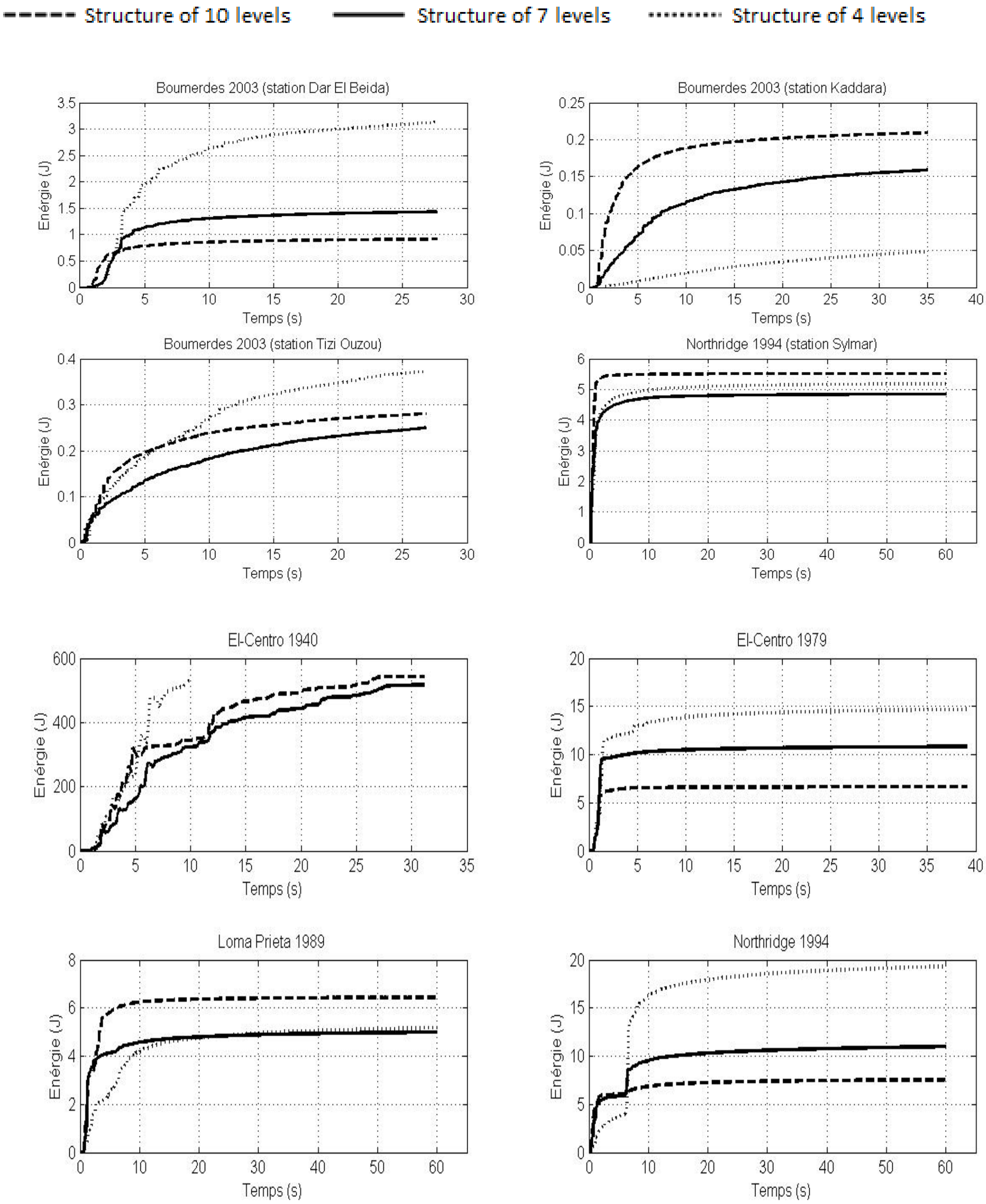

Figure 6. Absorbed energy by the isolation system in the structures of 4, 7 and 10 levels

COMPARISON OF DISPLACEMENTS

In order to compare the displacements of the last two levels of the structures, we chose three isolated structures of 4, 7 and 10 levels.
Figures 7 to 9 illustrate the displacements in function of time of the last two levels of the structures.

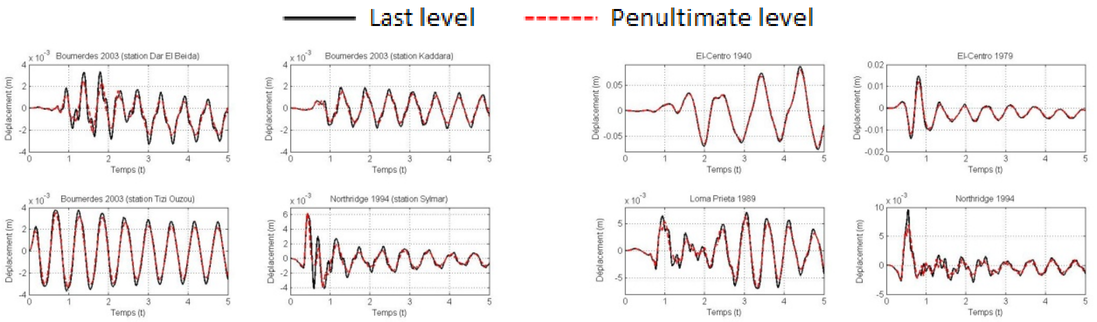

Figure 7 Comparison of displacements of the last two levels of the structures of 4 levels

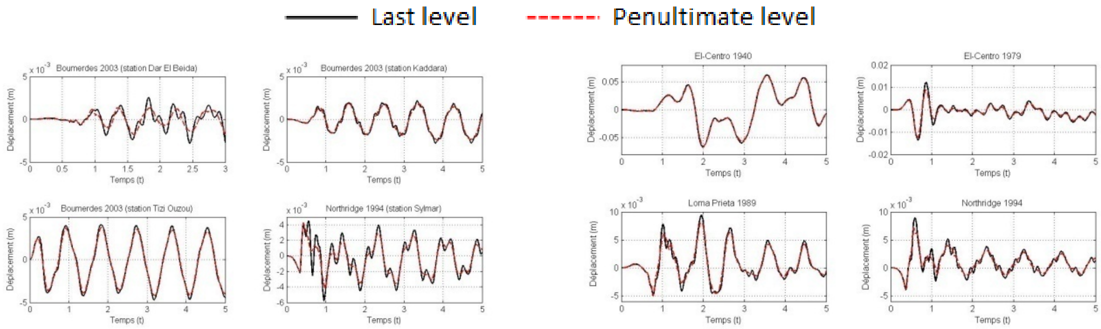

Figure 8 Comparison of displacements of the last two levels of the structures of 7 levels

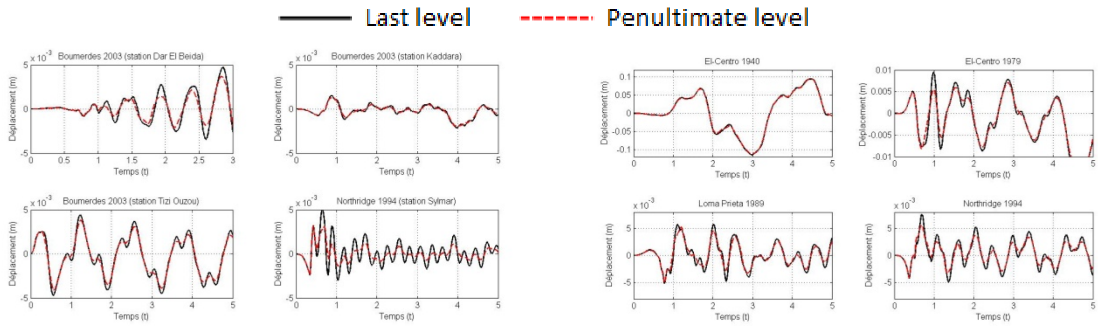

Figure 9 Comparison of displacements of the last two levels of the structures of 10 levels

COMPARISON OF ACCELERATIONS

In order to compare the accelerations of the last two levels of the structures, we chose three isolated structures of 4, 7 and 10 levels.

Figures 10 to 12 illustrate the accelerations in function of time of the last two levels of the isolated structures of 4, 7 and 10 levels.

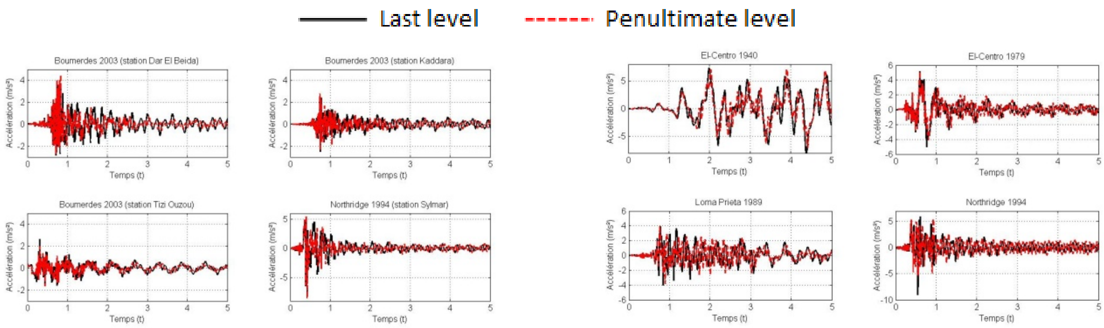

Figure 10 Comparison of accelerations of the last two levels of the structures of 4 levels

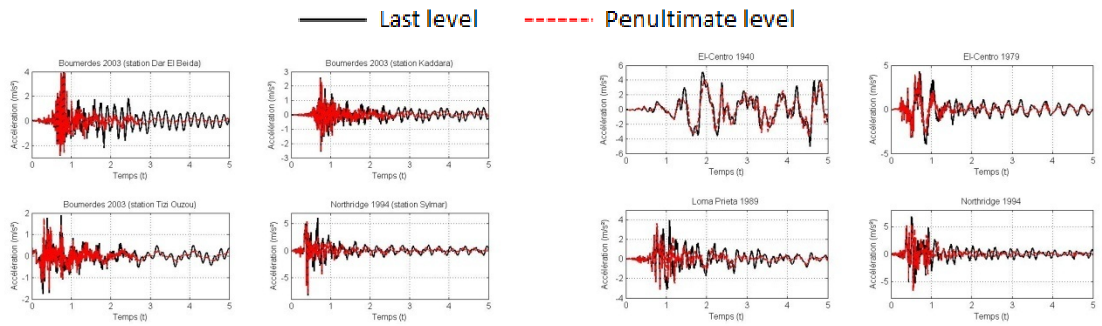

Figure 11 Comparison of accelerations of the last two levels of the structures of 7 levels

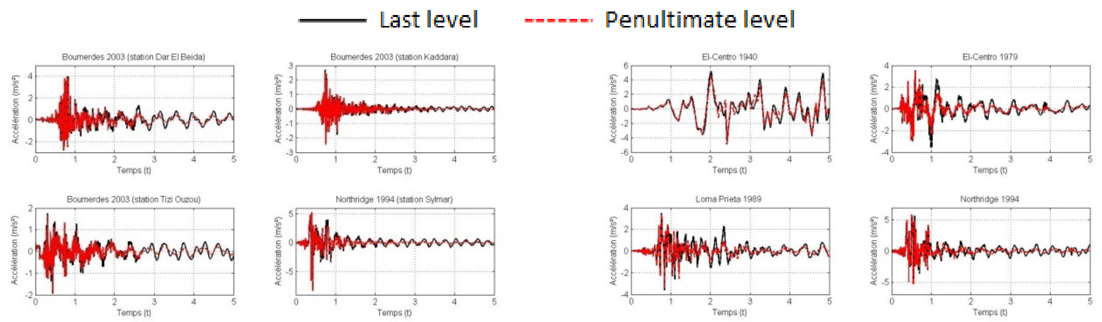

Figure 12 Comparison of accelerations of the last two levels of the structures of 10 levels

INTERPRETATIONS

According to Figure 5, we note that the maximum displacement of the seismic bearings are important under the effect of the Northridge earthquake 1994 (Newhall Station), and that this displacement increases gradually as the height of the isolated structure increases, it should be noted that the northridge earthquake is a strong earthquake, characterized by high amplitudes at low frequencies, from Figure 4 we see on the accelerogram Newhall several peak amplitudes in the interval from 0.5 to 1.8 Hertz, this interval coincides with interval which contains the frequencies of isolated structures (0.54 to 1.98 Hz), which explains these large displacements, thus we find that the seismic isolators work suitably under the effect of strong earthquakes and which has a rich frequency content at low-frequency.

However the displacements of seismic bearings are very low under the effect of the 2003 Boumerdes earthquake (Station Keddara and Tizi Ouzou), the maximum displacement is almost the same for all the structures. These earthquakes are characterized by low amplitudes, the natural frequency of these structures varies between 0.54 and 2 Hz in this interval the amplitudes recorded are very low, this is the reason why practically seismic isolators have not worked, so we concluded that the isolators are not effective under the effect of low earthquakes.

We also note that under the effect of Loma Prieta earthquake (Hollister), Northridge (Sylmar) and El centro, seismic bearings worked moderately, their maximum displacements vary according to the height of the structures (natural frequency of the structure) and the frequency content of these earthquakes.

The isolation system dissipates the induced energy by earthquakes before that this energy is transferred to the structure, from Figure 6 we note that the dissipated energy by seismic isolators varies from earthquake to other.

For Keddara and Tizi Ouzou accelerogram, the dissipated energy in the structures of 4, 7 and10 levels is very low which implies that the isolators have not worked.

For the accelerogram of Sylmar and the accelerogram of Hollister, the dissipated energy by the isolators is average, this energy varies slightly between the structures of 7 and 10 levels, this indicates that these isolators have worked in the same way under two different demands, so we can say that the isolation system in this case is less effective for slender structures.

For the accelerogram of Elcentro and Newhall, the dissipated energy by the isolators are important, this energy varies proportionally with the height of isolated structures, more the height increases more the seismic demand increases and the isolators dissipate energy, in this case the isolators worked in a progressive manner, thus we find that the isolation system dissipates more the induced energy by the strong earthquakes.

According to figures V.6, V.7 and V.8 we noticed that the inter-stage displacement is lower in isolated structures 3 and 7 levels it means that these structures vibrate almost as a rigid body and undergo less deformations of the fact that the horizontal displacements of these structures are approximately the same over the entire height, The result is that the displacement amplification are considerably reduced, contrariwise for the isolated structures of 10 levels the interstage displacement becomes greater, the isolated structures vibrate from one side to the other with the displacements amplification what causes damage to these structures. Similarly from Figures V.9, V.10 and V.11 we note that the acceleration in the last level are almost equal to the acceleration in the penultimate level for isolated structures 4 and 7 levels, contrariwise for the isolated structures of 10 levels the acceleration in the last two levels are different, this is due to an amplification of the accelerations. In addition we note that the isolation system becomes more efficient in the case of the strong seismic movements, because by being deformed it reduces the amplification of the accelerations, and consequently the displacement amplification in the isolated structures. On the other side, in the case of seismic movements of moderate or low intensities, the deformation of the isolation system is small and therefore the structures undergo amplifications of accelerations in the higher levels and significant relative movements between levels. This is due to lengthening of the period, and the influence of the isolation system on the frequency content of the structure, which results in translation to the lower frequencies.

CONCLUSION

The comparison of the responses of these structures under the effect of different earthquakes allowed us to have a general idea of the influence of frequency content of earthquakes on seismic responses of isolated structures. The main results are:

Seismic isolators work primarily under the effect of strong earthquakes and which have rich frequency content in the low-frequency. The overall response of isolated buildings decreases as the period of the earthquake decreases relative to that of the isolated building. The isolation system dissipates more energy induced by strong earthquakes. The isolation system is less effective in the case of slender structures. Finally, we believe we have clarified the influence of the base isolation on reducing seismic demands, and we conclude that it would limit the number of levels of isolated structures between 4 and 8 levels in order to have a better performance. The evolution over field of the use of the isolation technique, leads us to suggest the adoption of this new technology in the future Algerian earthquake resistant regulations RPA99/version2003.

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