Ninth Canadian Conference on Earthquake Engineering
Ottawa, Ontario, Canada
26-29 June 2007

DYNAMIC RESPONSE OF A BUILDING WITH BASE ISOLATION FOR NEAR–FAULT MOTIONS

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ABSTRACT

Most of the Argentine Republic territory may be considered seismic. Greater Gran Mendoza, an important socio – economic area in the Mid – Western region is one of the greatest seismic risks in the country. In the last 200 years or so, there have been important earthquakes affecting building structures. Consequently new techniques aimed at controlling vulnerability must be developed. An investigation of the actual application of Basal Seismic Isolation (BSI) on a building belonging to the Technological National University (UTN) is implemented. An analytical research of the isolation system on occasions of near – source motions has been done. The aim is to control BSI displacement. The strategy proposed was to add damping to the isolation system within certain limits and the results are compared to similar fixed – base building. To control near – source displacements, damping addition is an applicable and economic strategy. Although with this strategy there is acceleration increase, it is remarkably less than in the case of fixed – base buildings.

Introduction

Isolation systems have had an important development in the last few years. The response of a base-isolated building to important earthquakes (Northridge, 1994 and Kobe, 1995) was remarkable (Clark et al, 2002). In Japan, due to the positive response of these buildings, their number grew from 100 in 1995 to about 600 in 2000 (Clark et al., 2002). In the USA, though there was a similar response, the growth in number of this type of building was less than in Japan.

The density and importance of seismic instruments on the American West coast gave reliable records of near–fault events. Such records raised important questions about the reliability of seismic isolation in near–fault location buildings (Heaton et al., 1995). Uniform Building Code (UBC) of 1997 was based on the studies of these records and, consequently, it fixed even a more stringent design for near–fault base isolated buildings (Jangid et al. 2001).

Mendoza, in the western region of Argentina, presents some records of near-fault seismic movements. In this paper an investigation of Basal Seismic Isolation (BSI) on a building belonging to this area is presented. Spring and viscous-elastic dampers have been used as isolation system.

Isolation System

The system consists of four spring isolators and four viscous-elastic dampers (Figs. 1 and 2). These springs are grouped into a pack whose design is a function of vertical and horizontal stiffness and static and dynamic load capacity produced by area earthquakes.

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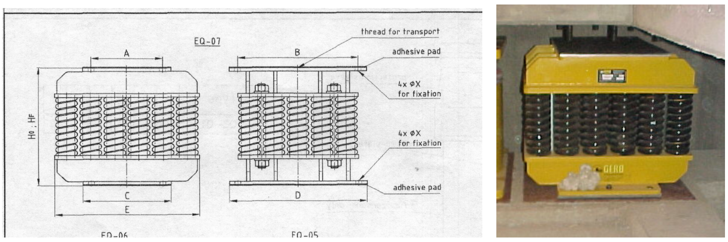
The spring isolators have low horizontal frequencies of about 1.00 to 1.5 Hertz and vertical frequencies of about 3.00 to 3.50 Hertz. These dynamic properties produce vertical and pendular movements in response to the ground-motion input. Horizontal strengths and amplitudes change into pendular and vertical displacements which reduce dynamic strengths in building structure.



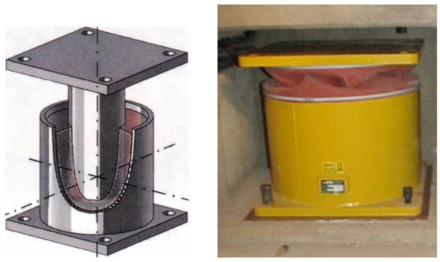


Figure 1. Springs Isolator.

Figure 2. Viscous-Elastic Dampers.

Together with spring isolators, viscous-elastic dampers are used. Viscous-elastic dampers (Fig. 2) are designed based on ground motion velocity in the area. Such a design allows damping variation within a specific range which provide damping in the three directions The role of these viscous-elastic dampers is to provide damping to the isolation system.

For a zonal ground motion, viscous-elastic dampers have been designed to provide 26% of longitudinal input and 13% of vertical input.

Near - Fault Motions

Structure damage is a function of the distance between building location and fault rupture. For near-fault structure, damage is due to few severe cycles of inelastic deformations which coincide with velocity peaks of important amplitude and normal to fault direction. When the structure location is far from the fault, damage is due to several inelastic displacement cycles (Frau et al., 2003).

The presence of important amplitude pulses is due to the effect of rupture direction (Somerville, 1996) which occurs in the presence of two conditions: 1) if the rupture line coincides with the record stations locations, an 2) if fault-rupture direction is aligned with it.

Rupture propagation velocity is similar to that of shear waves. They make rupture energy to arrive as an only long-duration pulse which presents itself a few seconds after the beginning of the record. This pulse is oriented perpendicularly to fault-sliding. In general, the presence of long-duration pulses, velocity and displacements produce greater demands of basal forces, floor drift and lateral displacements.

In this paper the response of isolation system in terms of displacements is evaluated using inputs from near-fault motion earthquakes.

The selected earthquake motions for isolated system response evaluation were taken from Worlds Collapse Accelerograms (WDA) data base, because they represent the most important seismicity characteristics of Mendoza. In all cases, record stations are located near the fault and at a distance not greater than 15 Km and the selection took into consideration ground characteristics (see Table 1).

In Table 1, P_D, Destructive Potencial (Araya and Saragoni, 1984). Ground classification based on United States Geological Service (USGS) criteria, whose limits are included in Table 2.

Earthquakes listed in Table 1 present important values of acceleration, velocity and displacement. These earthquake evidence small differences absolute acceleration spectra and Pseudo-accelerations spectra (Fig. 4). There are important differences between velocity spectra and pseudo-velocity spectra (Fig. 5).

A research carried out to evaluate base-isolated system response using near-fault motions found the same results (Jangid et al., 1999). The difference between velocity spectra and pseudo-velocity spectra depends on the systems natural period (Chopra, 1995).

Table 1. Near-fault motions.

Event	Date	Station	Comp.	Mag	Epicentral Distance (km)	Ground	P_D (cm-s)	PGA (g)	PGV (cm/s)	PGD (cm)
Tabas Iran	16/09/78	Tabas 9101	TR	7.4	3.00	Soft	13.2	0.85	121.4	94.60
Imperial Valley	15/10/79	Bond Corner	230º	6.9	2.50	Soft	24.9	0.78	45.90	14.90
Coalinga	22/07/83	Transmitter Hill	360º	5.7	9.20	Rock	4.70	1.08	39.70	5.40
Loma Prieta	17/10/89	Corralitos Eureka	N-S	7.1	5.10	Firm	8.40	0.64	55.20	10.90
Loma Prieta	17/10/89	Los Gatos	Fault Normal	7.1	3.50	Firm		0.72	173	64.70
Cape Mendocino	25/04/92	Cape Mendocino	N-S	7.0	8.50	Rock	4.90	1.50	127.40	41
Northridge	17/01/94	Tarzana Cedar Hill Nursery	E-W	6.7	17.5	Firm	32.4	1.78	113.60	33.20
Northridge	17/01/94	Rinaldi Receiving Station	228º	6.7	7.10	Soft	11.1	0.84	170.30	33.40
Kobe	17/01/95	Kobe Observat. JMA	N-S	6.9	0.60	Firm	20	0.82	81.30	17.70
Chi-Chi Taiwan	29/09/99	TCU084	E-W	6.9	10.40	Firm	11.6	1.16	114.7	31.40
Duzce Turquie	12/11/99	Lamont375	N-S	7.3	8.20	Firm	7.90	0.97	36.50	5.50

Table 2. Ground Classification (USGS).

Ground	USGS Classification	Wave Velocity Shear
Rock	A	> 750 m/s
Firm	B	360 a 750 m/s
Soft	C y D	< 360 m/s

Fig. 3 represents P_D, PGA, PGV and PD values for all selected earthquakes.

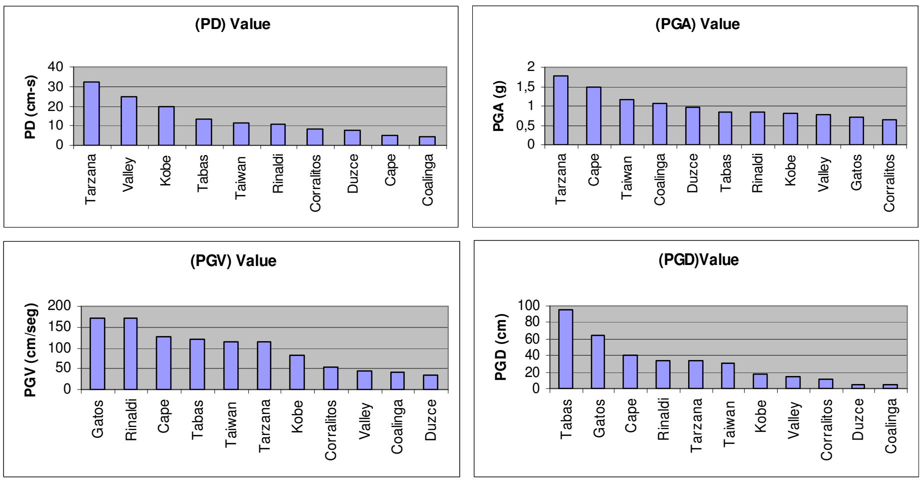


Figure 3. Velocity, acceleration and displacements ranger.

For long periods, pseudo-velocity is less than velocity. In Fig. 4, absolute acceleration elastic spectra and pseudo-accelerations spectra are plotted for 5, 10, 15 and 26% damping. It is observed that there are little differences between acceleration spectra and pseudo-acceleration spectra. The greater the damping value, the fewer the differences.

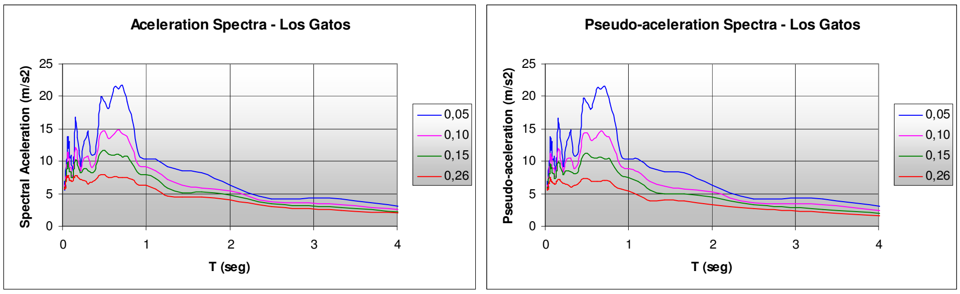


Figure 4. Acceleration spectra and pseudo-acceleration spectra for near-fault Motions.

In Fig. 5, velocity spectra and pseudo-velocity spectra are plotted for 5, 10, 15 and 26% damping. It is observed that there are differences between velocity spectra and pseudo-velocity spectra.

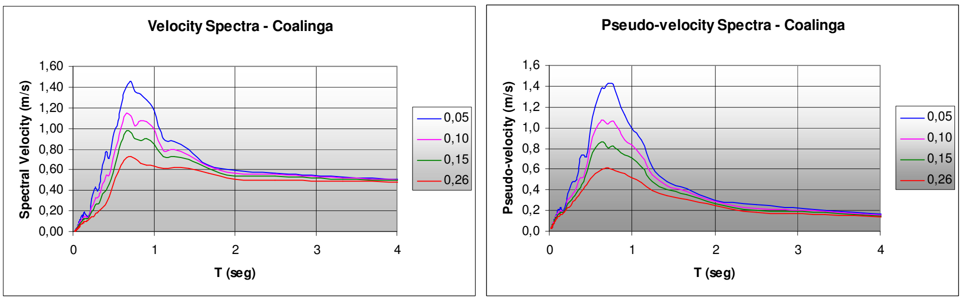


Figure 5. Velocity spectra pseudo-velocity spectra for near-fault motions.

In Fig. 6, elastic displacement spectra are plotted for 5, 10, 15 and 26% damping.

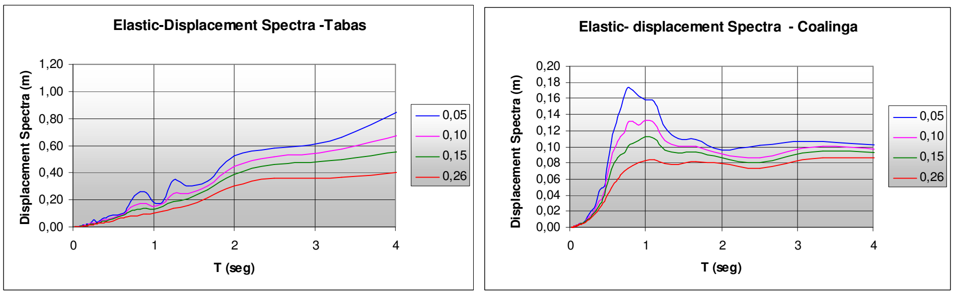


Figure 6. Elastic-displacement spectra for near-fault motions.

Characteristics of Seismic Isolation Structure and Systems

The analysed structure corresponds to one of the three-level tower belonging to Regional Faculty of Mendoza, UTN (Argentina) (Tornello M. et al., 2003). The structure is constituted by reinforced concrete columns and beams, masonry joint walls reinforced with a steel net on exterior and interior faces. Precast slabs with a surface of 4.00 cm reinforced concrete were used. Building plant dimensions are 7.60 m. by 8.10 m. Building fundamental period is 0.15 sec. (fixed base). And its total weight is 2600 KN. In order to evaluate dynamic response a 3D model was used and a linear time-history was analysed. In this analysis three records of near-fault motion were included. In Fig. 7 the 3D model is plotted.

Structural response was evaluated using a linear analysis of the isolated system (Nawrotzki, 2001). Dynamic characteristics of the system are listed in Table 3.

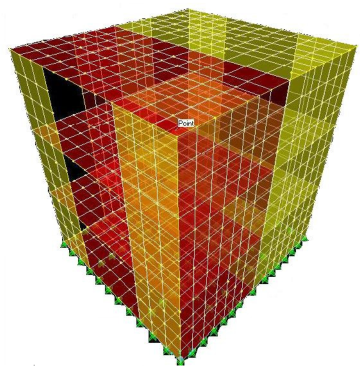


Figure 7. 3D Model finite elements Used in the Analysis.

Table 3: Dynamic Characteristic of the Isolation System used (SP and EVD).

Parameter	Value
Vertical load nominal capacity	768 KN
Vertical stiffness	29500 KN/m
Horizontal Stiffness	3940 KN/m
Longitudinal damping	26%
Vertical damping	13%

Vertical and horizontal stiffness is 7.50, which represents a very low value when compared to elastomeric isolation with lead core (Tornello et al., 2003). Building isolations systems (SP and EVD) period is 1.00 sec. The study has been carried out trough an analytical model with 3D finite elements. This study consisted in a lineal analysis in time history and earthquake accelerograms listed in Table 1 are introduced as excitation inputs which have not been scaled because it was important to know the actual response of isolation system. Analytical model of visco – elastic dampers and lead-core isolator are represented in figure 8 and 9 respectively.

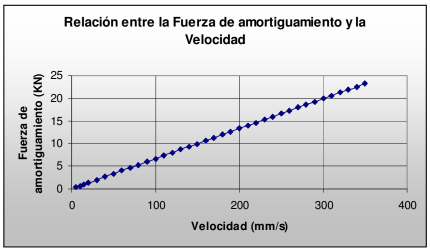


Figure 8. Analytical model of visco-elastic dampers.

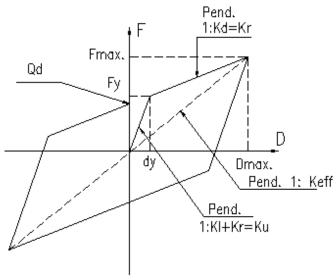


Figure 9. Analytical model of lead-core isolator.

For important displacement pulses of near-fault motion, damping increment of the isolation system might be an acceptable option so as to reduce displacement and to reduce costs of the great dimension elastomeric isolation manufacturing (Jangid R.S. et al. 2001). Damping is in direct relationship with the acceleration affecting the superstructure. For damping lower than 20%, and greater than 30%, the acceleration affecting the structure increases and depends on the period of the isolation systems and the earthquake frequency.

Other researchers (Madden et al, 2001) have introduced a greater damping to the superstructure. They found that there was a reduction of displacement, acceleration and floor drift. The fact that the fundamental building period is far from earthquake periods does not guarantee structure protection due to the presence or higher natural frequencies creating resonance. On the other hand, not all earthquakes show a predominant period with spectral peaks which can introduce dynamic amplifications (Bosso et al., 2000). For this reason damping increase of the isolation system may be a strategic tool to reduce structural response.

Results

In order to design the isolation system, two possibilities were evaluated: a) elastomeric isolator with lead core (E-I), and b) Spring packs with elastic viscous dampers (SP and EVD). In the near-fault motion earthquake analysed (Table 1) various results were obtained. The average of SP and EVD displacements were 34% of corresponding to E-I displacements, E-I reduce seismic acceleration more efficiently SP and EVD, but this latter system has better response than a base fixed building. In base-fixed building acceleration increment of 800% occurred between the base and the superior level. Acceleration reductions in E-I system were an average of 300% in SP and EVD systems, maximum shear forces and maximum normal forces showed a reduction of 46% for a first level column referred to the base-fixed building. For the same column E-I system reduces 42% of the maximum bending moment and SP and EVD system reduces 49%. Base horizontal reactions were 36% for SP and EVD and 15% for EI referred to the fixed-base building. Base vertical reaction were 80% for SP and EVD and 0% for EI. In this paper the results referred to fixed-base building were not included due to reason of extension.

When the building is near to the fault, code regulations (UBC) are more for design of isolation systems. These code regulations are high and conservative. Investigations carried on near-fault motions (Jangid et al., 2001) normal and parallel oriented to the fault indicated that displacements in the direction normal to the fault are highly greater than the parallel ones peak values of displacements occur at different times. The same effect can also be observed in the case of near-fault motions not normal and parallel oriented to the fault, except one of them in which maximum displacements occurred at the same time (Northridge earthquake, Rinaldi station). Such a response should be further investigated. Table 4 lists peak displacements and time reference for Sp and EVD.

In Fig. 10, time history of peak displacements can be viewed. These data confirm the results arrived at by Jangid et al. (2001) *"…the design displacements for the isolation system will not be vectorial sum of the maxim in each direction, but simply that in the fault normal direction "*.

The results of Jangid et al. (2001) investigations were also verified on near-fault motions not normal and parallel oriented to the fault on the earthquake included in this paper (Table 1).

Table 4. Peak Displacements on each Cross Component and Time Reference.

Event	ux (cm)	T (seg)	uy (cm)	T (seg)
Los Gatos	9.86	9.73	5.51	10.54
Rinaldi	8.64	2.82	18.9	2.82
Cape Mendocino	7.98	2.95	4.20	2.99
Tabas. Iran	4.10	38.02	18.90	37.30
Taiwán	6.49	42.01	18.40	37.29
Tarzana	6.48	6.87	12.70	8.64
Coalinga	6.68	3.74	4.58	4.16
Imperial Valley	6.38	8.03	6.15	7.64
Corralitos	5.64	2.57	7.05	3.98
Kobe	13.90	5.61	15.47	5.72
Duzce	1.50	18.30	2.26	25.71

The above results can be confirmed in the observation of peak displacements in both directions at the time of occurrence. When the peak displacement occurs in one direction, the displacement on the other direction is not a peak displacement (see Fig. 11).

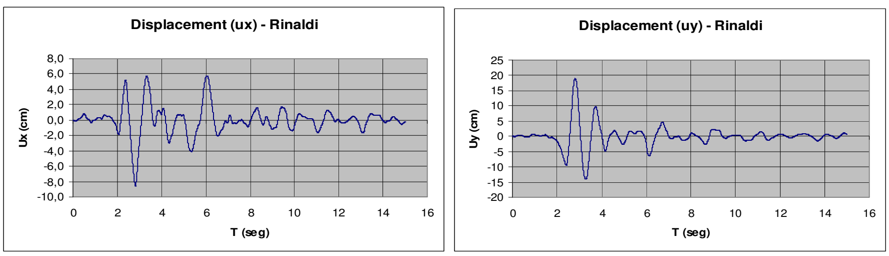


Figure 10. Time History of Peak Displacements.

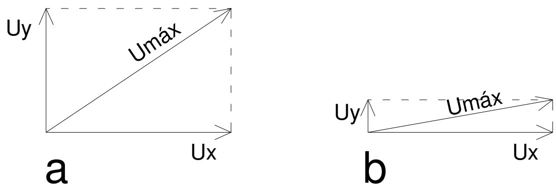


Figure 11. a) Peak Displacements on both Directions (UBC-97) - b) Analytical Peak Displacement.

Table 5 includes peak displacements in one direction and in both direction for SP and EVD.

Table 5. Peak Displacements in one Direction Compared to the Perpendicular.

Event	U_{max} (cm)	$U_{perpend.}$ (cm)
Los Gatos	5.5	4.15
Rinaldi	18.9	8.64
Cape Mendocino	6.6	4.20
Tabas. Iran	18.9	0.66
Taiwan	18.4	0.41
Tarzana	12.7	3.87
Coalinga	5.56	4.58
Imperial Valley	6.14	3.25
Corralitos	7.04	1.73
Kobe	15.5	9.88
Duzce	2.26	0.45

In Fig. 12, the peak displacements in one direction compared to the perpendicular in SP and EVD systems can be viewed.

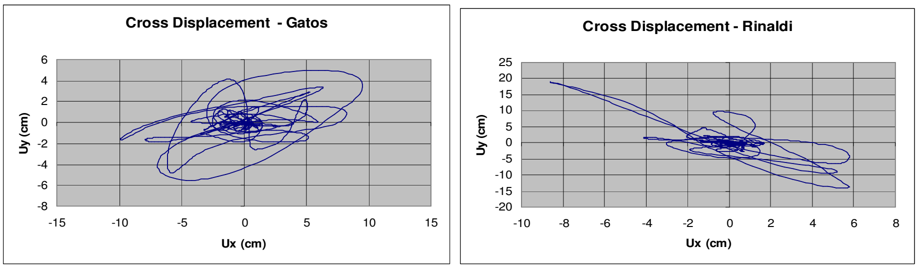


Figure 12. Peak Displacements in one Direction Compared to the Perpendicular.

In order to evaluate the response of the isolated system (EI) with lead core a non-lineal analysis was performed (Naeim F. et al., 1999). In the system SP and EVD an analysis was performed admitting a lineal behaviour force-displacement. In Table 6 the values of building that have peak force for one direction are summarized for (SP – EDV) and for damping values of 26% horizontal and 13% vertical.

Table 6. Peak Forces and Associated Displacements (SP and EVD).

Event	F_{max} (KN)	Ux. (cm)
Los Gatos	1469	8.93
Rinaldi	1292	7.87
Cape Mendocino	1198	7.33
Tabas. Iran	613	3.77
Taiwan	970	5.89
Tarzana	966	5.87
Coalinga	1015	6.16
Imperial Valley	952	5.78
Corralitos	849	5.22
Kobe	2072	12.55
Duzce	224	1.37

In Fig. 13, Force - Displacement hysteretic cycles are shown for SP and EVD system. In it, its lineal behaviour can also be seen. In Fig.12 Force - Displacement hysteretic cycles are shown for (EI) system. In it, its no lineal behaviour can also be seen.

In Table 7, the values of building base peak force for one direction are summarized for (EI) with lead core system and for damping values of 15% horizontal. In Fig. 14, Force-Displacement hysteretic cycles are shown for EI with lead core system. In it, its non-lineal behaviour can also be seen.

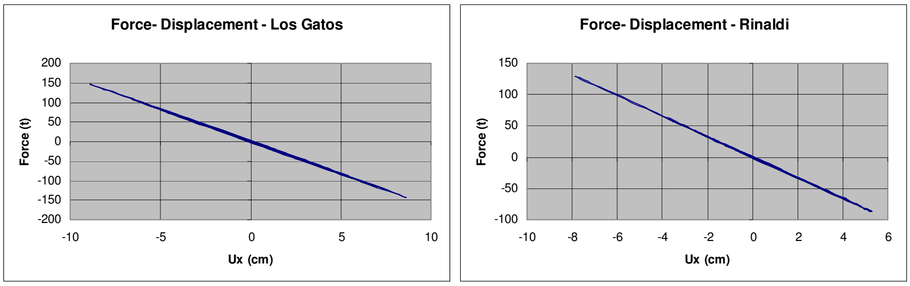


Figure 13. Force-Displacement Hysteretic cycles for SP and EVD system.

Table 7. Peak Forces and Associated Displacements (EI with lead core).

Event	F_{max} (KN)	Ux. (cm)
Los Gatos	561	29.5
Rinaldi	388	20.6
Cape Mendocino	430	20.2
Tabas. Iran	475	30.5
Taiwan	376	11.7
Tarzana	362	9.55
Coalinga	381	5.20
Imperial Valley	333	6.63
Corralitos	331	7.94
Kobe	311	10
Duzce	245	15.3

Investigations carried on near-fault motions normal and parallel oriented to the fault (Jangid et al., 2001) indicated that with the increase of damping coefficient of isolation system, the super structure acceleration decrease and, later on, increase after a certain value. In the case of the earthquake motion used in this paper, which are not normal and parallel oriented to the fault, the above phenomenon was only observed in three of the earthquakes (Cape Mendocino, Tarzana and Coalinga), while in the rest, accelerations tend to decrease and are constant from a certain damping coefficient.

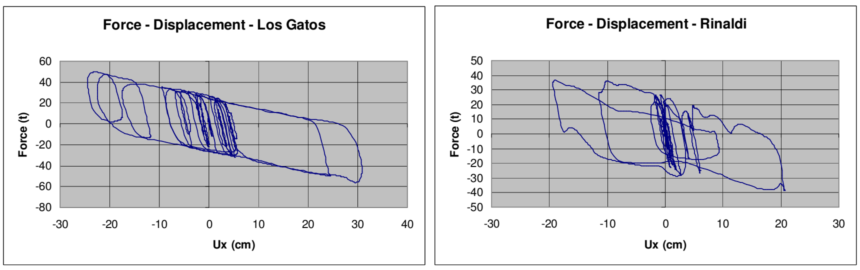


Figure 14. Force-Displacement Hysteretic cycles for (EI) whit lead core system.

The SP and EVD system can be designed with different damping values, changing the number of internal cylinder, which allows such damping coefficients on the three directions. Based on this property, the response of the isolation system was evaluated in terms of displacement and acceleration by varying damping. In Fig. 15 acceleration variations for various damping coefficients are shown.

The investigation carried on near-fault motions normal and parallel oriented to the fault (Jangid et al., 2001) demonstrated that displacement decreases when system isolation damping increases. The same effect was observed in the analysed earthquake (Table 1) which is not normal and parallel oriented to the fault. Consequently it might be expected that damping value of the isolation system was governed by acceleration value reading the super structure and not by displacement.

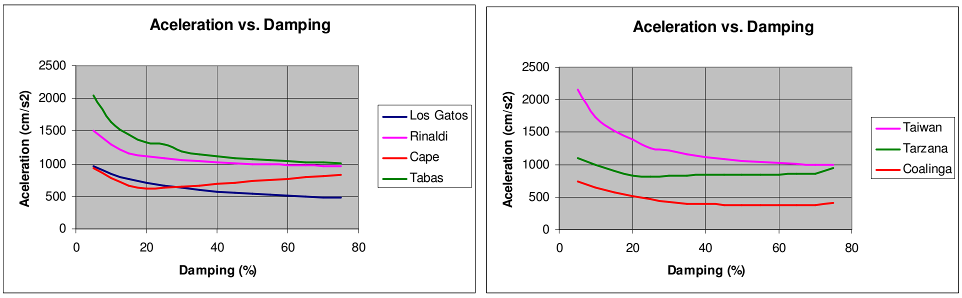


Figure 15. Absolute Acceleration variation in Super Structure vs. Damping.

In Fig. 16 displacement variation for SP and EVD system versus damping is plotted.

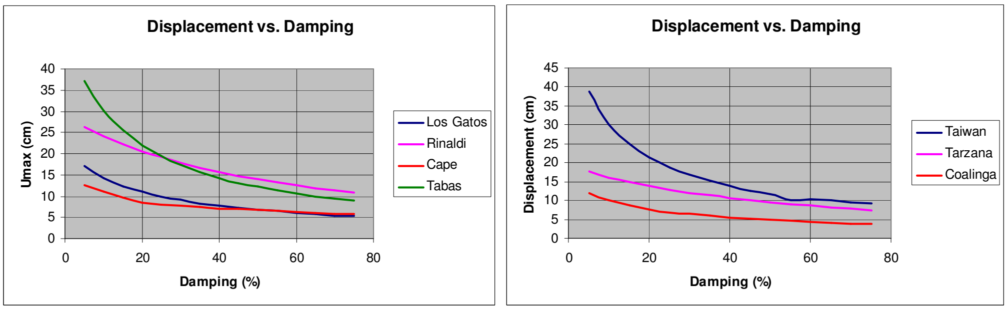


Figure 16. Displacement variation for SP and EVD system vs damping.

Conclusions

Isolation systems are more convenient for high-value periods in the spectrum. In many cases, isolation system response depends upon pulse-velocity, consequently to design the isolation system it is necessary to take into account the difference referred to in 1).

Depending upon frequency contents of near-fault motions, displacement spectra may be quite different. There exist some earthquakes (Coalinga) where maximum elastic displacement develops in less than one second.

Varying damping percentage referred to critic damping of the SP and EVD system acceleration values decrease (for a one-second period of the isolated building). It could not be proved that acceleration reading the super structure increases from a definite damping value (except Cape Mendocino, Tarzana and Coalinga).

Increasing damping percentage referred to critic damping of the SP and EVD system, displacement decrease (for a one-second period of isolated building). Consequently if it can be demonstrated that acceleration the superstructure increases from a definite damping value, damping that should be provided to the isolation system is controlled by acceleration.

In order to control displacements of near-fault motions (Table 1), increase of the isolation system damping is an economic and acceptable alternative. From this point of view, SP and EVD systems are of choice because damping value can be modified during designing. Elastomeric Isolation with lead core provides lower damping, it is not viscous, and it is not possible to modify the damping value. From the results of the present investigation, it is evident the advantage of the application of base isolation systems due to the reduction of accelerations in the structure and the strength on various structural members.

Acknowledgements

The present investigation has been benefited from the support of the authorities of the Mendoza Regional Faculty, Doctorate Program UTN, Investigators to Regional Centre of Technological Development and the valuable collaboration of GER Inc., Prof. M. R. de Romero and Jorge Marini.

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