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BEHAVIOURS OF ENERGY DISSIPATION DEVICES AND SEISMIC ISOLATION IN PRESENCE OF NEAR-FAULT GROUND MOTIONS

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ABSTRACT:

In areas near-source the effect of directivity produces strong motions records with long velocity pulses and a high amplitude and important displacements. The constructions submitted to this type of earthquakes must be capable of supporting big deformation and dissipate important quantity of energy in few cycles and short time. To mitigate the destructive effects of the earthquakes in general, there have been developed in the last decades devices of dissipation of energy and seismic isolation. Contradictory opinions exist with regard to the efficiency of this type of devices for to earthquakes near-fault. The objective of the work is to evaluate numerically the response of two types of devices of seismic protection subject to earthquakes of near-fault. The distinctive characteristics of the earthquakes of near-fault describe a suitable set of records which are to selected to the analysis of numerical models. Buckling restrained braces are selected as devices of dissipation of energy, as well as system of hybrid isolation composed by spiral springs of steel and visco elastic dampers. Non linear dynamic analysis of simple models is carried on with the devices of seismic protection. The results show that there is not a single ground motion parameter to characterize the responses of the two structure with protection devices studied. A great variability of selected response parameters is observed.

KEYWORDS: near-fault, isolation seismic, energy dissipation.

1. INTRODUCTION

Ground motions close to a fault rupture can be significantly more different than those farther away from the seismic source. The near-fault zone is typically assumed to be within a distance of about 15- 20 km from a fault rupture. Within this near-fault zone, ground motions are significantly influenced by the rupture mechanism, the direction of rupture propagation relative to the site, and possible permanent ground displacements resulting from the fault slip (Stewart et al. 2001). Ground Motions near-fault is typically characterized by a motion pulse-type of short duration and large amplitude. This motion concentrates the input energy to the structures in a few pulses at the beginning of the record. Structures placed in near-fault zones need special considerations in the seismic design (Alavi & Krawinkler, 2001). In the near-fault region, structural damage occurs for one or two severe cycles of inelastic deformation. These cycles correspond to ground motions with long and large pulses of acceleration, velocity and displacement. Ground motions with directivity pulses can generate a much higher base shear, inter-story drift, and roof displacements in high-rise buildings compared with ground motions that does not contain these pulses. The ductility demand can also be much higher and the effectiveness of supplemental damping can be much lower both for pulse-like ground motions (Malhotra, K., 1999). In high-rise buildings, ground motions with large pulses of velocity and displacement cause in the structural response a large participation of higher modes (Iwan et al. 2000). There exist numerous studies and applications related to the structural response with seismic isolation, nevertheless, few researcher bear in mind seismic sources characteristics (Martelli et al., 2005). The displacement of the isolated structures subject to near-fault ground motion is strongly influenced by one of the of the ground motions components (Jangid R. S. et al., 2001). Investigations in structures with natural rubber bearing isolators subject to near-fault ground motion indicate that an increase in the damping of isolation devices achieve minor displacements, inter-story drift, seismic base shear, accelerations and velocity (Wolf E. D. et al., 2004). Investigations realized by Naeim F. et al., 1999 indicated that increasing the damping of the isolation device, reduces the displacement but increases the accelerations and inter-story drift. Nevertheless, there is no indication of the seismic parameter controlling the structural response when the record possesses long pulses of velocity and displacement or how to control the dimensions of the isolations system before the presence of the mentioned pulses. Numerous analysis and design procedures for structures with passive energy dissipation systems are present in specialized literature (Hanson and Soong, 2001). There are documents and standards which establish requirements for such structures (AISC 341, 2005). But there are not many developments about the dissipation devices requirements in structures which could be submitted to near-fault ground motion. The aim of this paper is to evaluate the response of two types of seismic protection devices subjected to near-fault ground motion. The characteristics of the near-fault ground motion are presented. A set of this type of ground motion is selected for numerical analysis. We considerer two structures: one with passive energy dissipation devices; and the other with a hybrid isolation system composed by steel springs and visco elastic dampers. Non linear time history analysis were carried out. The incidence of soil movement parameters on the structure responses with both types of seismic protection devices were also studied.

2. NEAR-FAULT GROUND MOTIONS SELECTED

In this paper a set of eleven near-fault ground motion records with epicentral distance lower 20 km have been selected. Records are part of World Collapse Accelerograms database developed by Saragoni and Rojas (2000) and updated for Hernandez and Saragoni (2002). This database exclusively contain records of zones where structural collapse was verified. These records are adequate to carry out non linear analysis because it is accepted that its action caused important non linear deformations in real buildings. Table 2.1 shows the set of records selected and the principal parameters used in this study.

Table 2.1: Ground Motion Parameters

Event #	Earthquake	Date	Mom. Mag.	Station Name	Component	PGA	PGV	T_V	PGV/PGA	MVGV	Dq
						cm/s^2	cm/s	s	s	cm/s	cm
1	Tabas Iran	09-16-78	7.4	Tabas 9101	Transv.	0.85	125.2	2.31	0.15	164.9	95.2
2	Imperial Valley	10-15-79	6.9	Bonds Corner	230º	0.78	45.9	1.07	0.06	83.6	22.4
3	Coalinga	07-22-83	5.7	Trasmitter Hill	360º	1.08	39.6	0.84	0.04	62.2	13.0
4	Loma Prieta	10-17-89	7.1	Corralitos	N-S	0.64	55.5	0.64	0.09	82.9	13.3
5	Loma Prieta	10-17-89	7.1	Los Gatos	FN	0.72	172.8	2.84	0.24	268.7	190.9
6	Cape Mendocino	04-25-92	7.0	Cape Mendocino	N-S	1.50	125.2	3.35	0.09	164.5	137.7
7	Northridge	01-17-94	6.7	Tarzana Cedar Hill Nursery	E-W	1.78	113.3	0.79	0.06	194.5	38.4
8	Northridge	01-17-94	6.7	Rinaldi Receiving Sta.	228º	0.84	165.6	1.25	0.20	238.3	74.5
9	Kobe	01-17-95	6.9	Kobe Observatory of JMA	N-S	0.82	81.3	1.85	0.10	158.3	73.2
10	Chi Chi, Taiwan	09-20-99	7.6	TCU 084	E-W	1.16	114.6	1.83	0.10	125.8	57.4
11	Duzce, Turquía	11-12-99	7.3	Lamont 375	N-S	0.97	36.5	0.35	0.04	61.1	5.3

3. STRUCTURE WITH ENERGY DISSIPATION DEVICE

In this section we study a steel frame described by Hanson and Soong (2001). The dimensions of the frame are 1.32 m for 1.32 m in plan, and 5.69 m in height. The mentioned authors evaluated the frame, with and without visco elastic and friction devices. A scaled 1940 El Centro earthquake with 0.6g peak acceleration is considerer as the design earthquake. For the present paper a study of this frame was carried out with buckling restrained braces (BRB), AISC 341, 2005. They constitute one type of passive energy dissipation devices. These devices contribute to the dissipation of the energy entering the structure during an earthquake. They can be build with low cost and with basic technology, even in countries with emergent technologies. The BRB was designed so that the inter-story drifts were similar to the indicated by Hanson and Soong (2001) for the structure with visco elastic devices. In addition to the El Centro earthquake we considered the earthquakes described in the section 2. These acelerogramas were named as C.M.1 y C.M.2 for the Cape Mendocino (Cape Mendocino and Petrolia station), I.V. for the Imperial Valley (Bonds Corner station), L.P. for the Loma Prieta (Corralitos station), Northr.1 and Northr.2 for the Northridge (Rinaldi and Simi Valley station).

The response parameter considered was the roof displacement related to the frame's height, the inter-story drift, the seismic base shear, as well as bending and axial effort in one column of the first floor. A more detailed description about the design of the BPR and the structural response under the different earthquake can be found in Palazzo et al. (2008). The reduction of the structural response with BRP respect the free structure is shown in Figure 1.

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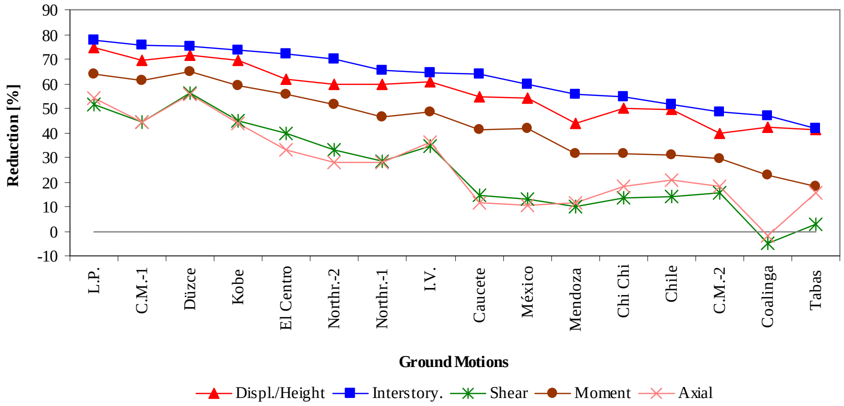
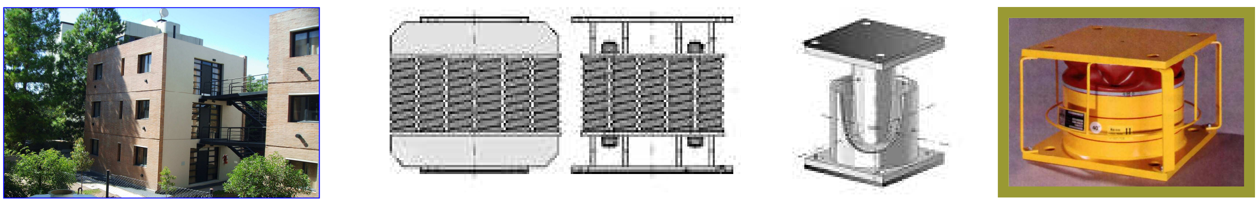


Figure 1: Reduction of the structural response with/without BPR

4. STRUCTURE WITH SEISMIC ISOLATION DEVICE

This building possesses three levels with concrete structure, masonry walls and concrete slab. Plant dimensions are 8.00 x 7.60 m. When a participation of 25% of the live load is assumed, the weight of the building is 2570 KN and 2910 KN when a participation the live load is 100%. The building period is 1.00 s with seismic isolation and 0.17 s, for the same building, but with fixed base (Tornello M. and Sarrazin M., 2007) (Figure 2.a). Seismic isolation device consist of four steel spring packages (GCS, GERB® Control Systems) and visco elastic dampers with vertical axis (Gerb Visco®) (Figure 2.b and 2.c). The devices installed correspond to the model EQ-07 with a vertical load capacity of 921 KN, a vertical stiffness of 35.40 KN/mm and a horizontal stiffness of 4.73 KN/mm. The damping design was 26 % in horizontal direction and 13 % in vertical direction. A model in finite elements in 3D was used in the design of the building with seismic isolation (Figure 3 Right). Damping force–Velocity ratio of the visco elastic damper is shown in Figure 3 Left.



(a) (b) (c)

Figure 2: (a) Building with seismic isolation. (b) Steel spring packages (GERB® Control Systems). (c) Visco elastic Dampers (GERB Visco®)

Structural response is obtained by time history non linear dynamic analysis. The software used for such target was the SAP2000 (CSI, Computer and Structures, 2003). The analysis is based on the proper of the viscous linear damping and not proportionality between the stiffness and mass. Is usual to carry out the direct equations integration of the of movement bearing in mind the forces in the isolator or in the viscous damper. In this case the unbalanced non lineal force in every time step are analysed by mean of a number of reduced structural modes (Stuardi et al., 2005). The method of direct integration of the equilibrium equations represents appropriately the behaviour of the seismic isolation but only it allows to analyse deterministic sign in the time dominion. Preliminary studies (Tornello and Sarrazin, 2007) compared the structural response obtained in theoretical form between the building with seismic isolation and another with fixed base of identical characteristics.

To obtain the structural response, the components of ground motions selected (Table 2.1) were considered to be seismic demands for the building. Some structural responses of displacements, inter-story drift and accelerations can be observed in Figure 4. A more detailed of the design in the isolation systems and the structural response obtained under different seismic records can be found in Sarrazin et al. (2007).

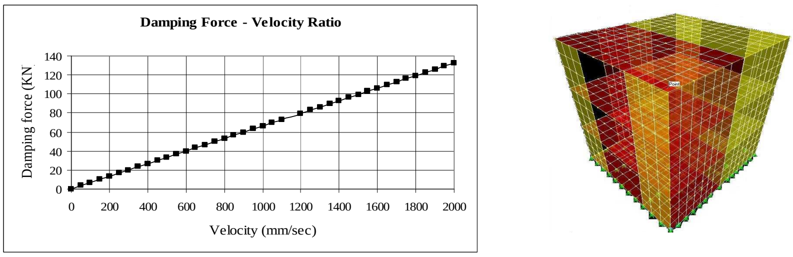


Figure 3: (Left) Damping Force – Velocity ratio (Right) Structural model

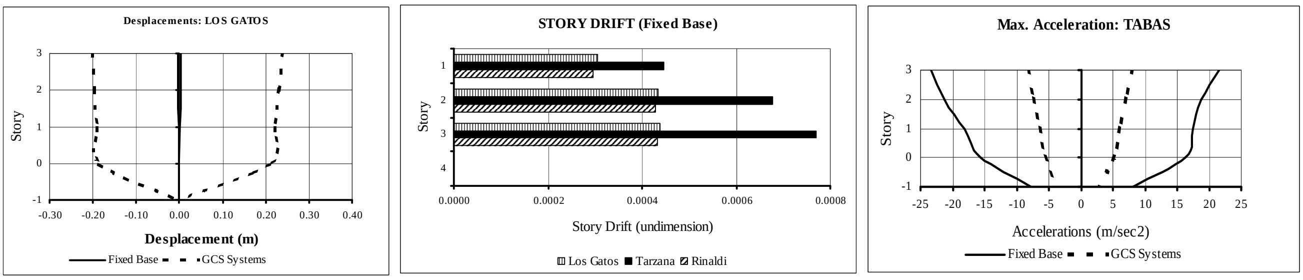
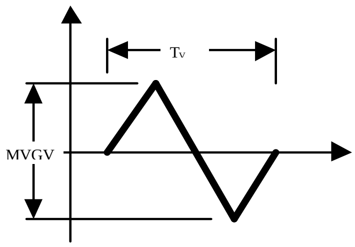


Figure 4: (Left) Horizontal displacements. (Middle) Story Drift. (Right) Horizontal Acceleration

5. NEAR-FAULT GROUND MOTIONS AND STRUCTURAL RESPONSE PARAMETERS

Several parameters have been used to characterize ground motion. The most familiar parameters are PGA, PGV and PGD (peak ground acceleration, velocity and displacement). Pulse-type motions have been identified as critical in structures design in the near-fault zone. The analysis of elastic and inelastic multiple degree of freedom systems indicates that the amplitude and period of pulse in the velocity-time history (A_v=PGV in these cases) and T_v are parameters that control the performance of structures (1, 2, 3). Lara et al. (2004) demonstrated that the Maximum Variation of Ground Velocity (MVGV) is an important cause of inelastic response for some structures. MVGV is the largest peak to peak value in the ground velocity. Malhotra (1999) showed that near-fault ground motion with directivity effects tend to have high PGV/PAG ratio. This ratio dramatically influences response characteristics. In this research a new parameter is proposed named Equivalent Displacement to the Maximum Velocity Pulse (DEQUIV). It is defined from the T_V and MVGV as the area of the a equivalent velocity pulse, triangular in form and whit an amplitude equal to MVGV/2, and a period T_V (Fig 5-Eqn. 5.1).



$$D_{EQUIV} = \frac{MVGV \cdot T_V}{4} \qquad (5.1)$$

Figure 5. Equivalent Displacement to the Maximum Velocity Pulse

Initially, several parameters were considered to characterize ground motion such as: PGA, PGV, PGD, T_V and MVGV. Some of them were combined parameter, such as PGV/PGA, PGV/PGD and D_{EQUIV}. Authors considered as the more significant parameter for the evaluation of the structural performance with seismic isolation: a) peak ground velocity, PGV; b) period of pulse in the velocity-time history, T_v; c) peak ground velocity peak ground acceleration ratio, PGV/PGA and d) Equivalent Displacement to the Maximum Velocity Pulse, D_{EQUIV}. For structures with energy dissipation devises: a) peak ground acceleration, PGA, b) period of pulse in the velocity-time history, Tv; c) peak ground velocity-peak ground acceleration ratio, PGV/PGA and d) Equivalent Displacement to the maximum velocity pulse D_{EQUIV}. Parameters used for evaluating the structural response in structures whit seismic isolation were: a) Normalised base shear, V_i /V_{min} and b) Normalised acceleration roof level Ai_{TOP} /A_{min}; where "i" denote response for ground motion "i", and "min" denote the lower response value. Parameters used for evaluating the structural response in structures with energy dissipation device were: a) Normalized base shear, V_i/V_{min}; b) Normalized displacement roof level, Di_{TOP} /D_{min} and c) Normalized acceleration roof level Ai_{TOP}/A_{min}.

6. RELATIONSHIP BETWEEN GROUND MOTION AND RESPONSE PARAMETERS

To evaluate the most suitable tendency between the input parameters and the response parameters, three types of relations, linear, logarithmic and polynomial were analysed. The study was completed by the evaluation of residuals distributions. The most suitable tendency lines were selected across the statistical parameter of R^2 and residuals distribution.

6.1. Structure with seismic isolation

For the Normalized shear base response (V_i/V_{min}) acceptable tendency lines were found for four parameters studied, Figure 8. When the values of (PGV), (PGV/PGA), (T_v) and (D_{EQUIV}) are increased the tendencies indicate increases of the values of (V_i/V_{min}) in some cases in linear form and in others in logarithmic form. The same result was found by the accelerations (A_{top}/A_{min}) in the roof of the building. The relationships found indicate an increase of the maximum accelerations in the roof of the building when the parameters that characterize the ground motions increase, Figure 6. The graphic representation of the information about the parameters that characterize ground motions and the response analysed indicate a very similar distribution for two response studied (V_i/V_{min}) and (A_{top}/A_{min}), Figure 6 and 7. The relationships corresponding to (PGV/PGA) and (T_v) show a tendency of linear increase for the two responses studied while, those of (PGV) and (D_{EQUIV}), indicate a logarithmic increase.
Acceptable interrelations were found in the cases studied but it is important to notice that the distribution of the points corresponding to (T_v) and (D_{EQUIV}) allows to infer, with certain clarity, a definite tendency. On the other hand, the parameters (PGV) and (PGV/PGA) present more dispersed distributions. This situation is observed for both response studied (V_i/V_{min}) and (A_{Top}/A_{min}).

6.2. Structures with Dissipation of Energy devices

The Figure 11 shows the relationships between the seismic base shear (V/V_{min}) and the ground motion parameters. Similarly, Figure 9 shows these relationships for roof displacement (D_{top}/D_{min}). For the acceleration roof this relationship is very similar (it's not drawn).
For the relationship between seismic base shear and roof displacement respect ground motion, trend with acceptable correlations for the PGA parameter was found. Thus, Figure 8 and Figure 9 show that if the PGA parameter increase, seismic base shear and roof displacement also increase (in a linear shape). For other earthquake parameters there are trend lines, but with large dispersions ($R^2 < 25\%$).

7. CONCLUSIONS

The results show that there is not a single ground motion parameter to characterize the responses of the two structure with protection devices studied. A great variability of selected response parameters is observed.
In general, for the structure with seismic isolation, an increase in the ground motions parameter indicate major values of structural response. For the cases studied, the parameters Tv and DEQUIV, present clearer tendencies for de shear base and the acceleration.
For the structure with BRB, if the PGA earthquake parameter increases, the response parameters also increase in a linear shape. With the other parameters that characterize the ground motion, trend with a high correlation was not found.

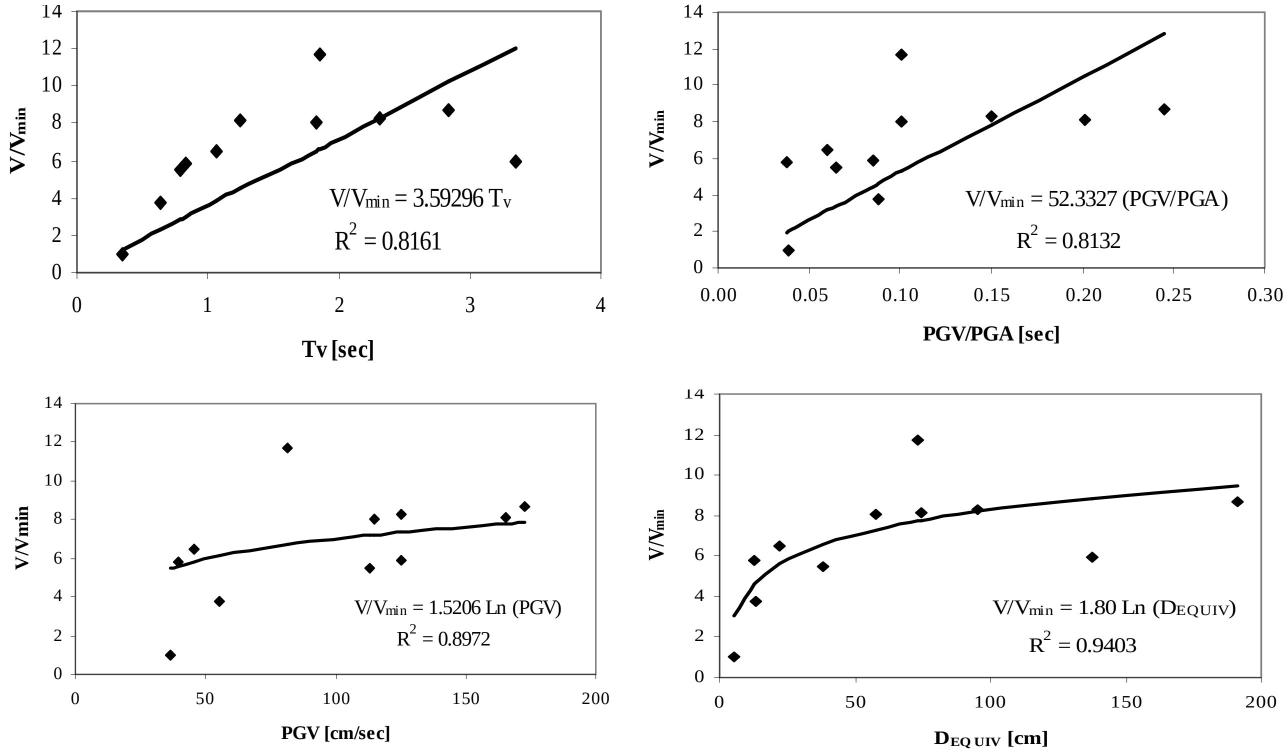


Figure 6. Relationship between parameters T_v, (PGV/PGA), PGV, D_{EQUIV} and (V/V_{min}) response.

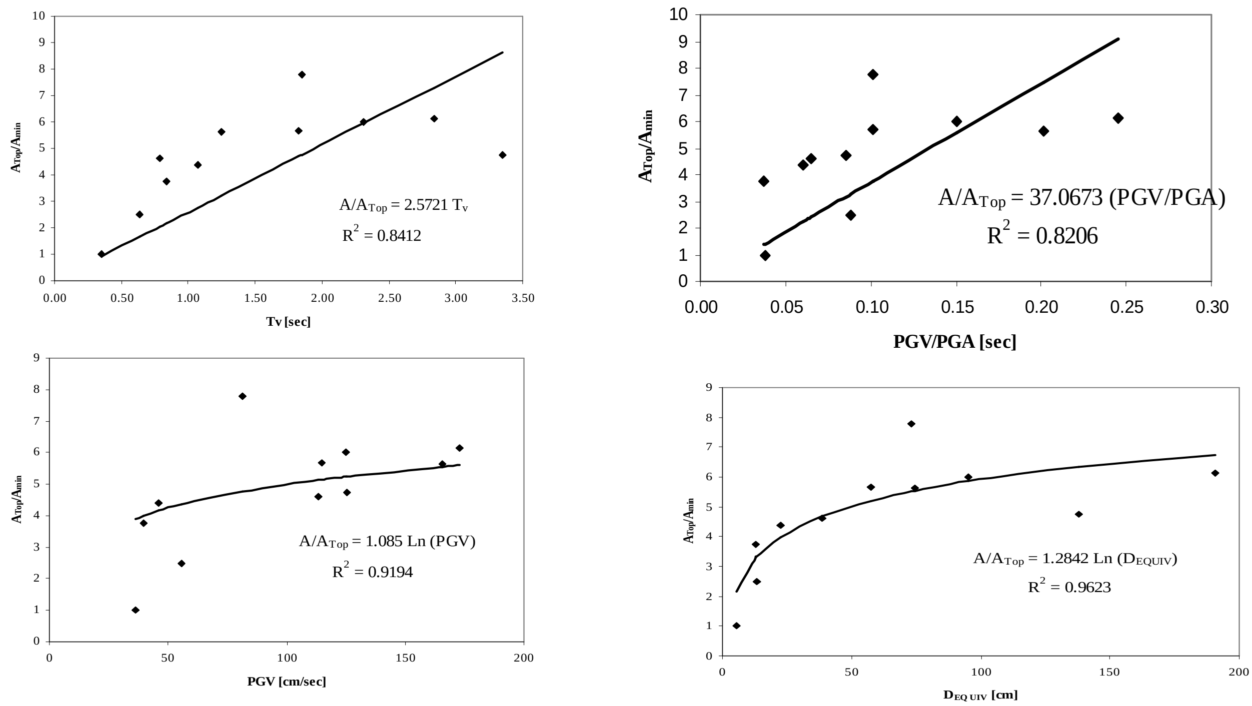


Figure 7. Relationship between parameters T_v, (PGV/PGA), PGV, D_{EQUIV} and (A_{Top}/A_{min}) response

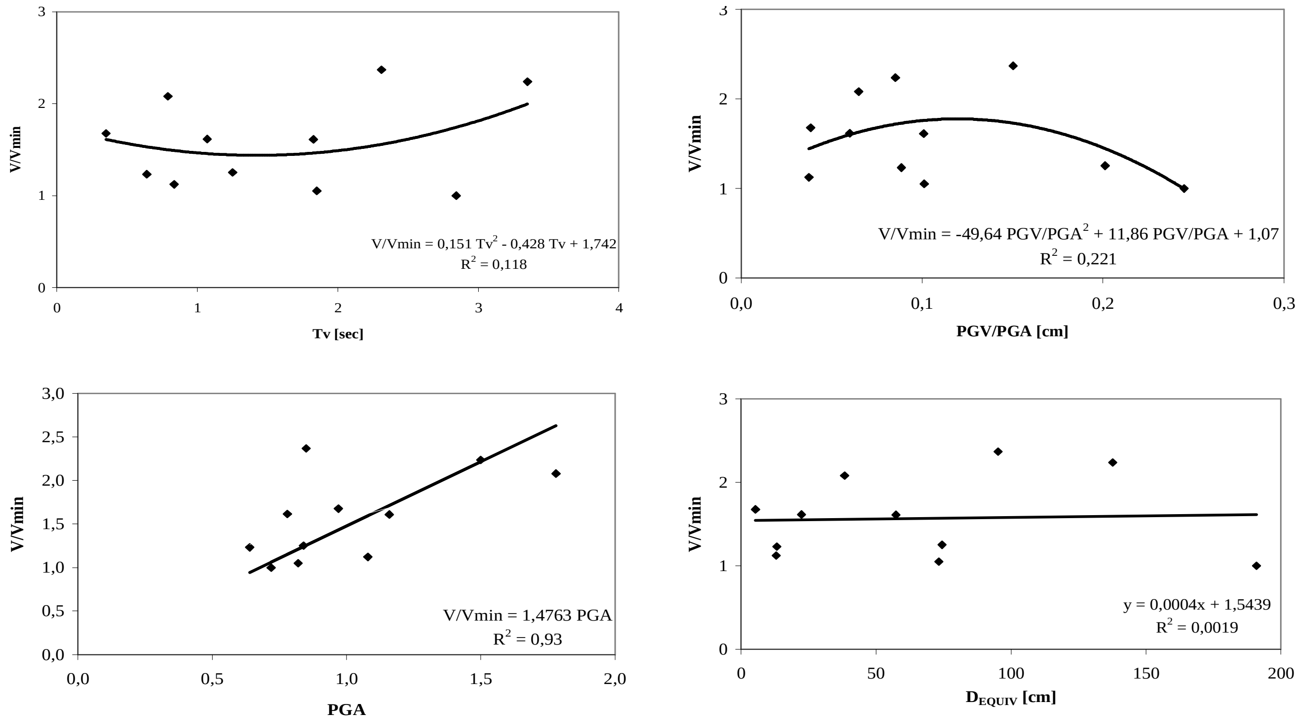


Figure 8: Relationship between parameters T_v, (PGV/PGA), PGA and D_{EQUIV} vs. (V_i/V_{min}) response

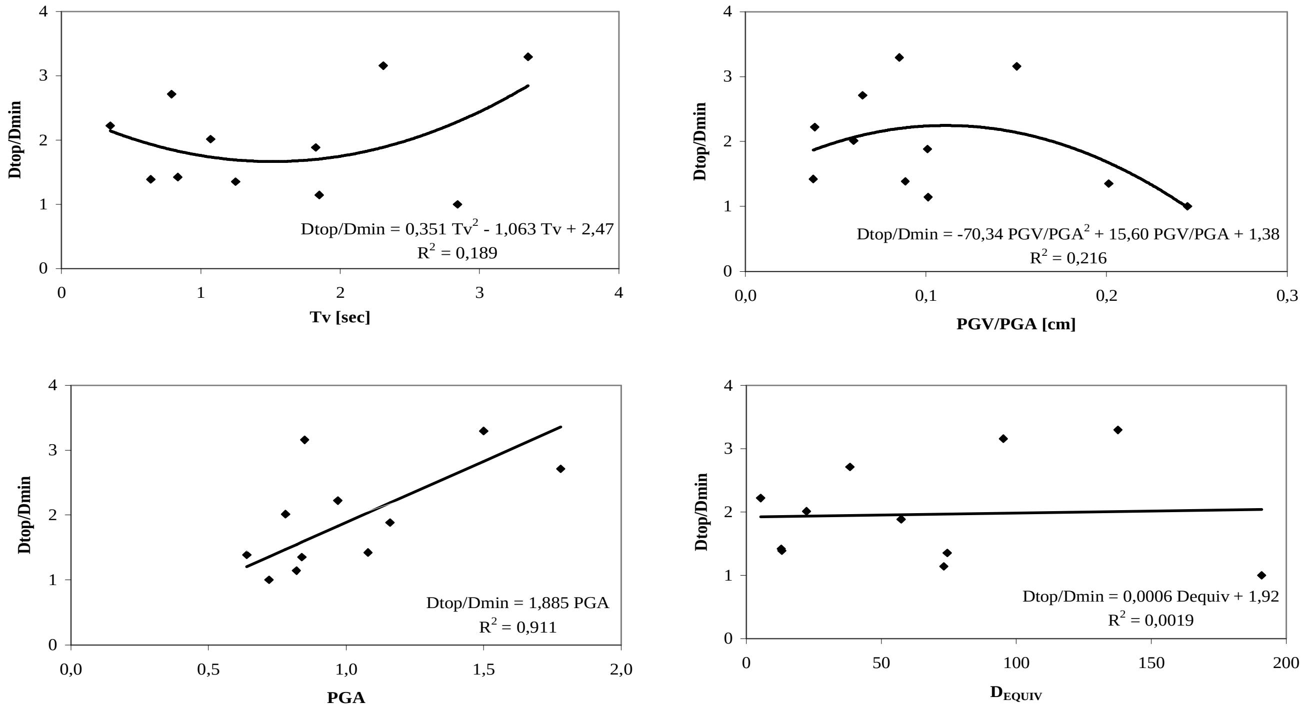


Figure 9: Relationship between parameters T_v, (PGV/PGA), PGA and D_{EQUIV} vs. (D_{top}/D_{min}) response

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REFERENCES

- AISC 341, (2005), Seismic Provisions for Structural Steel Building. *American Institute, of Steel Construction, Inc.*
- Alavi, Babak and Krawinkler H. (2001) Effects of Near-Fiedl Ground Motion on Building Structures. *CUREE Publication Nº CKIII-02. CUREE-Kajima Joint Research Program, Phase II*.
- CSI, 2000. Computer and Structures, Inc (2003). SAP 2000. V-9., Berkeley, California.
- Hernandez, J. M. and Saragoni, R. (2002). Estudio de la respuesta no lineal en condiciones de colapso sísmico. VIII Jornadas Chilenas de Sismología e Ingeniería Antisísmica. Valparaíso, Chile.
- Iwan, Wilfred D., Ching-Tung Huang and Guyaner A.C. (2000). Importance features of the Inelastic Structures to Near-Fiel Ground Motion. *12th World Conference in Earthquake Engineering*. New Zealand.
- Jangid R. S., Kelly J. M., (2001). Base Isolation for near-fault motions. *Earthquake Engineering and Structural Dynamics*. 30:691-707.
- Lara O., Parodi R., Centeno J. and Bertero V. (2004). Physical ductility demand spectra for earthquake ground motions containing severe pulses. *13th World Conference on Earthquake Engineering*, Vancouver, B.C., Canada.
- Malhotra, Praveen K. (1999). Response of building to near-field pulse-like ground motions. *Earthquake Engineering and Structural Dynamics*, 28, 1309-1326. John Wiley & Sons, Ltd.
- Martelli, A., (2005). Modern Seismic Protection Systems for Civil and Industrial Structures. *Congreso Chileno de Sismología e Ingeniería Antisísmica. IX Jornadas. Chile. CD. ISSN 0718-2678.*
- Naeim F.; Kelly J. M., (1999). Design of Seismic Isolated Structures. Edit. John Wiley & Sons, Inc. Printed in the United States of America.
- Palazzo, G., Crisafulli, F., and López Almansa. F. (2008). Simulación numérica de estructuras reforzadas con disipadores de energía sometidas a excitación sísmica. *Congreso sobre Métodos Numéricos y sus Aplicaciones, ENIEF 2008, Argentina.*
- Saragoni, R. y Rojas M., (2000). Análisis de la potencia sísmica de acelerogramas destructivos. XXIX Jornadas Sudamericanas de Ingeniería Estructural, Punta del Este, Uruguay.
- Sarrazin M., Moroni M. O., Boroschek R., Herrera R., Roschke P., Tornello M. (2007). Research Activities in Chile and Argentina on Base Isolation passive energy dissipation and vibration control. *10th World Seminar on Seismic Isolation. Energy Dissipation and Active Vibration Control of Structures. Istanbul. Turkey.*
- Stewart, J. P. et al. (2001). Ground Motion Evaluation Procedures for Performance-Based Design. PEER Report 2001/09.
- Stuardi J., Massa J., Brewer A. (2005). Eficiencia de Sistemas de Aislamiento Sísmico basados en resortes helicoidales y amortiguadores viscosos comparada con aisladores tradicionales goma – metal. *VIII Congreso Argentino de Mecánica Computacional*. *CD*. Argentina. Facultad de Ingeniería y Ciencias Exactas y Centro de Estudios Avanzados Universidad Argentina de la Empresa.
- Tornello M. E., Sarrazin A. M. (2007). Dynamic Response of a Building with Base Isolation For Near – Fault motion. *9th Canadian Conference on Earthquake Engineering*. Paper Nº 1057. Ottawa. Canadá. (CAEE, ACEP).
- Wolff E., Constantinou M.C., (2004). Experimental Study of Seismic Isolation Systems with Emphasis on Secondary System Response and Verification of Accuracy or Dynamic Response History Analysis Methods. University at Buffalo, St. Univ. of New York. Dep. Civil , Structural-Environmental Engineering. *Tech Report MCRRT-04-001*.