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ANALYTICAL STUDY OF BASE ISOLATED BUILDINGS IN MEXICO

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ABSTRACT

The applicability of base isolation devices in typical public school structures in Mexico was analyzed. Three structural models of the three story building were considered according to the most possible seismic behavior related to the interaction of the structural and non structural members. The building is supported on moment resistant frames. This type of structure was very common before the 1985 Michoacán earthquake; after the earthquake, it was modified incorporating concrete walls in some bays. These structural systems are supported on moment resistant frames combined with concrete and non structural reinforced masonry walls.

Two types of isolators were selected: one with sliding characteristics and the other a friction type device. The friction isolator chosen is denominated Friction Pendulum System. The device consists of cilyndrical surface that produces a pendular movement of the building when it vibrates laterally. Building behavior over Lead Rubber Bearings that provide flexibility and energy absorbing capacity in a single unit was also analyzed. This kind of isolator has been extensively utilized for the seismic isolation of many buildings around the world.

The buildings were subjected to three seismic records of the 1985 Michoacán Earthquake corresponding to stations located near the epicenter on the Pacific Coast of México.

The design of isolators was developed using the 3D-BASIS program, as an iterative process, in order to fulfill the requirements of the Uniform Building Code (UBC) regulations and the recommendations of the Structural Engineers Association of California (SEAOC). Final isolator properties were selected, for each building, according to the structural response obtained under the three seismic records mentioned.

Results lead to the conclusion that base isolation is an attractive structural system to reduce the seismic response of low-rise buildings located on the pacific coast of Mexico. There was not a great difference in the building behavior when the structure was supported by friction or sliding isolators of the type studied in this analysis.

KEYWORDS

Base isolation devices; seismic behavior; friction type device; lead plug elastomer; friction pendulum system.

INTRODUCTION

We analyzed a typical public school building designed according to the Mexican regulation code of 1976. It consists of three levels, with interstory height of 3 meters. According to the adopted axis system, the building orientation in the longitudinal direction, is north-south (N-S). The structural system has two frames in the N-S direction (separated 8 m), and thirteen frames in the E-W direction (separated 3.24 m). The building plan is 39.64m x 12.4m with a roof area of 491.5 m2. The area of the lower levels is reduced due to the elimination of a cantiliver 1.2 m long.

The building doors and windows in the longitudinal direction are formed with half height walls of hollow block masonry. In transverse direction, the building have floor to ceiling walls of the same material, located every two bays, excluding the penultimate frame where the wall is located only on the first floor. This assymetrical distribution in plan originates excentricities that generate torsion. The floor system is a concrete slab 10 cm thick at the top level and 11 cm for the other levels.

Geometric properties of the columns are uniform in building plan and height, 30cm x 40cm rectangular section. The largest dimension corresponds to the building width. Girder dimensions vary depending on level and direction. In longitudinal frames, beams sizes are 20x51 cm and 25x47 cm for the first two levels and the roof, respectively. In transverse frames, beams sizes are 25x51 cm and 25x60 cm the first two levels and the roof, respectively. The structure foundation consists on concrete spread footings. The concrete's strenght was considered of f'c=200 kg / cm2 and the steel yield stress was fy=4200 kg / cm2. The properties of the masonry walls were taken according to the recommended design values of the Mexican regulation code.

ELASTIC ANALYSIS

Three building models were analyzed in order to consider three possible structural behaviors related to the interaction of the structural and non structural members of the building. The first one (EP3A) has full height transverse walls and half height walls in the N-S direction (walls where doors and windows are located) which are close enough to the columns and girders, so as to contribute to the stiffness of the structure. In the second model (EP3B), the half height walls are separated from the columns, so they do not contribute to the lateral stiffness of the structure. The third model (EP3C) was elaborated considering that both, transverse walls and half height walls are separated from the structure. Masses and weights used for the elastic analysis of the three models are shown in table 1.

Table 1. Masses and weights

EP3A y EP3B models			EP3C model		
Level	Weight (ton)	Mass (ton-s2/m)	Level	Weight(ton)	Mass (ton-s2/m)
3	330.71	33.71	3	311.37	31.74
2	397.70	40.54	2	397.70	40.54
1	397.70	40.54	1	397.70	40.54
Sum	1126.10	114.79	Sum	1106.77	112.82

Dynamic properties of the models were determined using the ETABS program (Habibullah et al, 1991). The first three periods and the mass participation factors are presented in table 2.

Table 2. Dynamic characteristics of the models

	EP3A Model				EP3B Model				EP3C Model			
Mode	Period	Modal mass			Period	Modal mass			Period	Modal mass		
		N-S	E-W	ROT.		N-S	E-W	ROT.		N-S	E-W	ROT.
1	0.59	90.57	0.00	0.05	0.79	89.06	0.00	0.00	0.78	82.93	1.52	4.68
2	0.33	0.01	64.68	21.43	0.34	0.01	63.28	23.06	0.76	5.68	44.14	39.94
3	0.30	0.01	22.55	66.07	0.30	0.09	24.24	63.83	0.72	0.54	39.12	44.99

As can be observed in table 2, the first modal shape of the EP3A model, is translation in the longitudinal direction; the second and the third modes are coupled shapes, the second with dominant movement in the transverse direction and the third mode with a rotary movement. Similar modal shapes were obtained with the EP3B model. The first mode of the EP3C model is coupled with preferential movement in the longitudinal direction, showing the load asymmetry. The second and third modes are also coupled with translation movement in the transverse direction and rotation, respectively.

When the E-W walls are joined to the structure (EP3B model), the stiffness is increased by 125%, which is reflected in the reduction of the second and third vibration periods. The period changes are from 0.76 and 0.72 to 0.34 and 0.30 sec. respectively. Upon considering the half height walls contribution (EP3A model), structure stiffness is increased by 33%, changing the period to 0.59 sec.

To study the base isolated structure two types of devices were considered: lead plug elastomer and friction pendulum system. The devices were located on the columns, between the first floor and the foundation. The design of the insolators was accomplished according to the recommendations of Skinner et al, 1993. The isolated structure was analyzed using the 3D-BASIS program (Nagarajaiah et al, 1991). The elastomers obtained are 40x55 cm in plan and 40 cm height and were oriented according to the column position.

The characteristics of the slide friction devices depend on the curvature radio. The isolators selected measured of 1.46 m, 1.41 m and 1.4 m, for the EP3A, EP3B and EP3C models, respectively. The radio and the contact surface determine the slip device force.

Displacements and shear forces of the three models with and without isolators are shown in Tables 3 to 8.

RESULTS

According to Tables 3 to 8, the isolated model responses are very similar no matter which isolator is used. Shear forces are practically the same in levels 2 and 3 for the three seismic records, presenting the largest difference on the first level, with CALES and UNION records. Base shear forces with friction isolators are about 30% smaller than those obtained with the lead plug bearings. These results can be attributed to the properties of the different isolators. While elastomers have elasto-plastic behavior, friction devices have rigid-plastic behavior that can originate the reduction of shear forces in the first level of the structure. With PAPNA record, shear forces are slightly increased with the used of friction devices, however in none of the cases the forces are greater than those obtained with the UNION record, for which the isolators were designed. The hysteretic behavior of an elastomer and of a friction isolator, roof relative displacements and relative accelerations of the EP3C model subjected to the UNION record are shown in figure 9.

CONCLUSIONS

The following conclusions were obtained according to the previous results. Base insolators moves the structure to spectral ordinates of lower amplitude, reducing the possibility of structural damage to buildings, for earthquakes records as the one used in this study. Isolators strongly reduced displacements, acceleration and shear forces. Story Displacements are reduced 50% with the UNION and CALES records and 30% with PAPNA record, when base isolators are incorporated to the building. Shear force reductions are about 50% in the isolated models, with the UNION and CALES records, and for EP3A model subjected to PAPNA record. The others isolated models under this record have similar shear forces with and without isolators, however these forces are always smaller than those corresponding to the UNION record, which was used to obtain isolator geometry.

The use of base isolators is recomended for structures located in places near the origin of earthquakes, as is the case of the Mexican subduction faults on the Pacific coast.

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Table 3. Maximum dynamic displacements (cm),
EP3A Model

Seimic record	Level	without isolators	sliding isolator	friction isolator
UNION	3	5.4	2.1	1.7
	2	4.3	1.7	1.3
	1	2.3	1.0	0.6
CALES	3	3.5	1.8	1.6
	2	2.8	1.4	1.4
	1	1.5	0.8	0.6
PAPNA	3	1.6	1.3	1.2
	2	1.3	1.0	1.0
	1	0.7	0.5	0.5

Table 4. Maximum shear forces (ton)
EP3A Model

Seismic record	Level	without isolators	sliding isolators	friction isolators
UNION	3	205.40	80.45	85.75
	2	390.70	154.53	134.05
	1	502.87	215.67	132.41
CALES	3	127.73	72.35	74.85
	2	255.89	133.96	134.60
	1	349.50	173.00	133.85
PAPNA	3	128.95	57.20	74.72
	2	269.62	99.22	126.47
	1	338.72	113.38	130.87

Table 5. Maximum dynamic displacements (cm),
EP3B Model

Seismic record	Level	without isolators	sliding isolators	friction isolators
UNION	3	8.5	4.4	2.9
	2	6.9	3.4	2.3
	1	3.6	1.7	1.1
CALES	3	6.4	3.4	2.5
	2	5.0	2.7	1.8
	1	2.5	1.4	0.9
PAPNA	3	3.1	2.2	2.2
	2	2.5	1.7	1.7
	1	1.3	0.9	0.9

Table 6. Maximum shear forces (ton)
EP3B Model

Seimic record	Level	without isolators	sliding isolator	friction isolator
UNION	3	172.60	99.86	91.98
	2	335.55	182.92	131.90
	1	494.27	222.38	152.01
CALES	3	144.89	77.26	80.93
	2	281.51	143.11	103.13
	1	334.51	192.54	116.51
PAPNA	3	67.46	62.82	74.84
	2	135.51	92.25	125.22
	1	174.14	118.38	129.25

Table 7. Maximum dynamic displacements (cm),
EP3C Model

Seimic record	Level	without isolators	sliding isolator	friction isolator
UNION	3	9.2	4.3	2.9
	2	7.4	3.4	2.2
	1	3.8	1.7	1.1
CALES	3	6.3	3.4	2.4
	2	4.9	2.7	1.8
	1	2.4	1.4	0.9
PAPNA	3	3.7	2.3	2.3
	2	2.7	1.8	1.7
	1	1.3	0.9	0.7

Table 8. Maximum shear forces (ton)
EP3C Model

Seimic record	Level	without isolators	sliding isolator	friction isolator
UNION	3	156.85	91.83	89.40
	2	344.58	181.25	128.18
	1	480.85	232.17	146.49
CALES	3	151.77	76.93	70.47
	2	280.01	140.08	100.98
	1	353.18	186.26	132.92
PAPNA	3	69.49	54.78	68.20
	2	135.34	102.36	104.60
	1	171.43	140.29	116.86

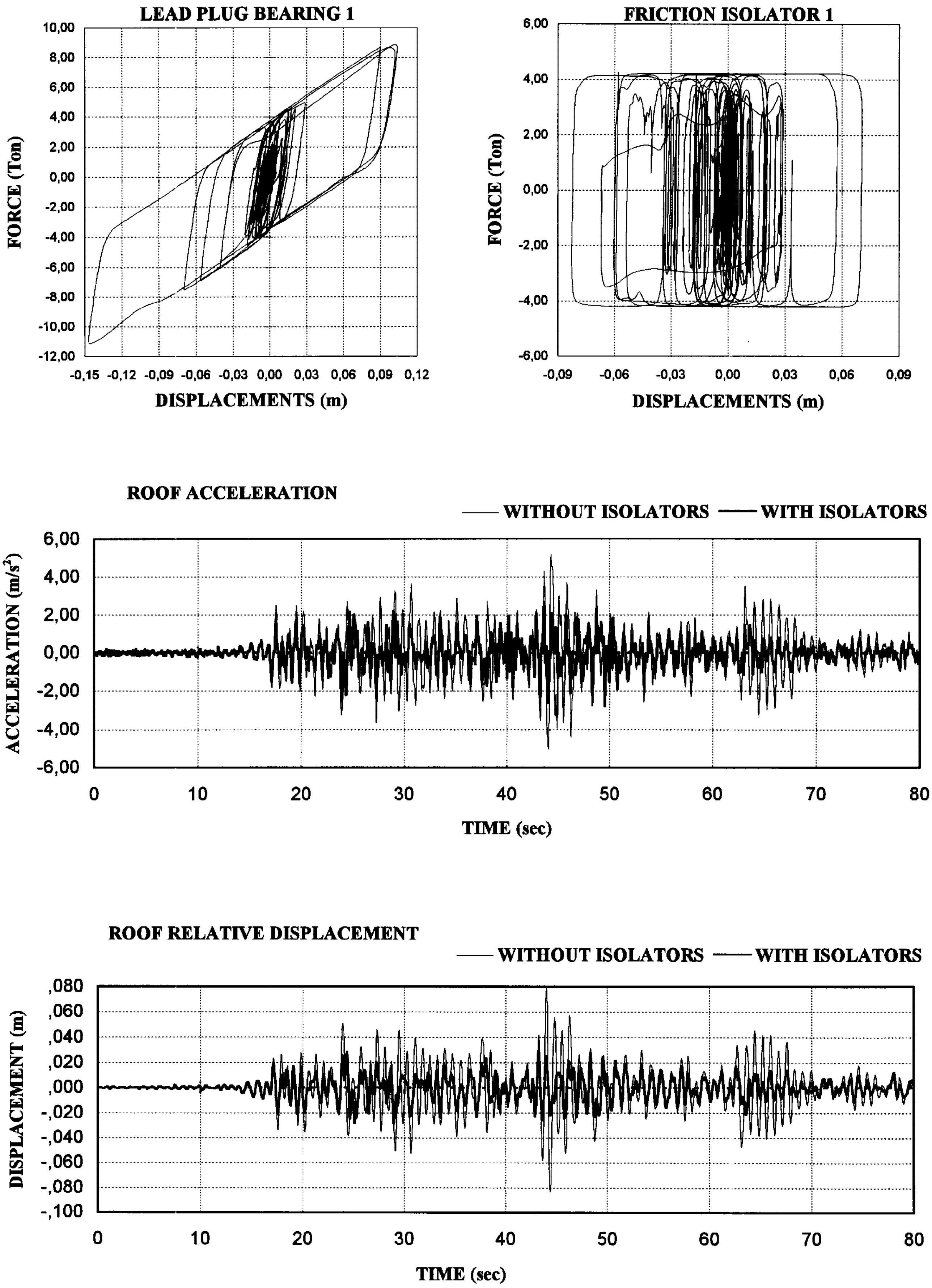

FIG. 1.- SEISMIC RESPONSE OF EP3C MODEL, UNION RECORD