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# Comparative study of isolated structures

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ABSTRACT: An experimental and an analytical dynamic analysis of an isolated building is done. The structure is reproduced by a three-dimensional model in a PC. Based on this, simplified models with non-linear behavior are analized. Different characteristics of the base dissipating system are studied in connection with the allowable base displacement of the structure. A comparative analysis of the response and costs of the structure with and without the isolation system is done. Results reveal that the shear force responses are reduced about 45%, and total costs are increase 5% when isolators are included in the structure.

## 1 INTRODUCTION

One of the first buildings on seismic isolators in the world was constructed in 1964, in Mexico City. This isolated building, as well as many others around the world have experienced no damage during different intense ground motions, including the Michoacan-Guerrero earthquake of 1985. Unfortunately, this building is not provided with any seismic instrumentation and no objective information about its behavior during earthquakes is available.

In this study an experimental model analysis is carried out by means of the ambient vibrations technique and a linear three-dimensional model of the building is developed and implemented in a personal computer (PC).

Based on this, simplified models with non linear behavior are analized. Different assumptions about the base dissipating system characteristics are made. Isolated and non isolated structures are excited with a family of scaled earthquakes recorded on the intermediate soil zone of Mexico City. Costs estimation of an isolated and a non isolated structure is done.

## 2 DESCRIPTION OF THE STRUCTURE

The building under study is a five floors reinforced concrete school with seismic rolling isolators (González-Flores, 1964). It is located on the intermediate soil zone of Mexico City. Its stories are 3 m high and its plan dimensions are 41.4 x 26 m (Figs 1 and 2). The structure has rectangular section columns (40 x 50 cm) and beams (30 x 70 cm) and a steel - slab floor system, except in the ground floor which consists of a reinforced concrete slab.

Between the foundation system and the upperstructure is placed the isolating device shown in Fig 3. This consists mainly of lubricated steel balls ($\phi$ = 11/32") confined laterally by steel rings of circular cross section and by steel plates which transmit the vertical load. The lateral building displacements are restrained by a base system consisting of diagonal steel cables and springs connected in series with the cables (see Fig 1). The behavior of this system is

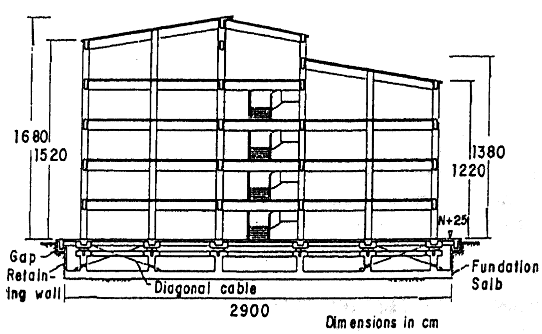


Fig 1 Lateral view of the isolated building

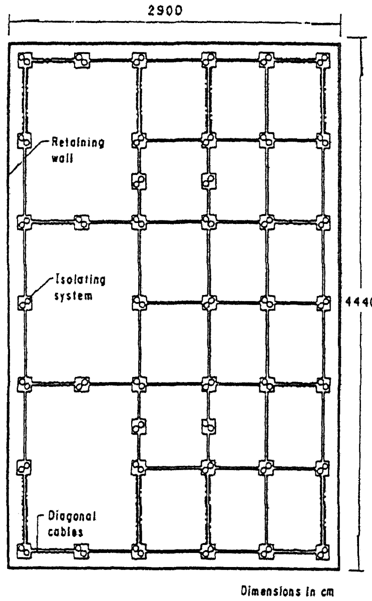


Fig 2 Foundation plant of the isolated building

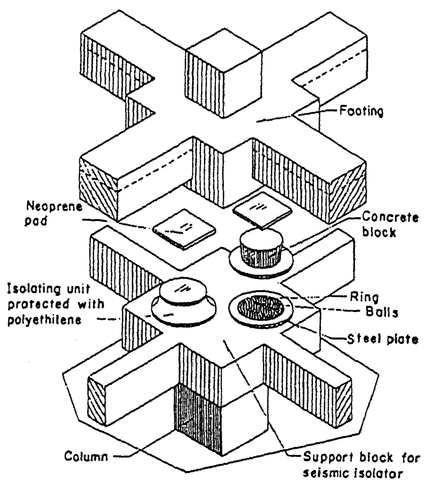


Fig 3 Isolating system between basement and upperstructure

bilinear elastic, without energy dissipating capacity.

In order to study the dynamic behavior of an improved structure, hysteretic dampers with bilinear inelastic force-deformation curves are assumed in this study.

3 AMBIENT VIBRATION RESULTS

The model shapes and frequencies of the

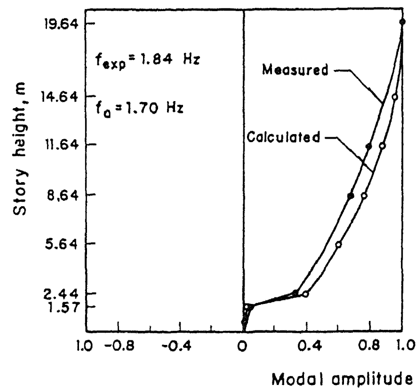


Fig 4 Fundamental mode of the structure

Table 1 Characteristics of the ground motions

| Record No. | Date | Coordinates Lat- Long | Max Spectr Acc./g |
|---|---|---|---|
| 1 | 80.10.24 | 18.440- 98.130 | .1535 |
| 2 | 85.09.19 | 18.182-102.573 | .1688 |
| 3 | 85.09.19 | 18.182-102.573 | .160 |
| 4 | 85.09.19 | 18.182-102.573 | .1694 |
| 5 | 85.09.19 | 18.182-102.573 | .160 |
| 6 | 85.92.21 | 17.300-108.230 | .0782 |
| 7 | 85.09.21 | 17.300-102.230 | .1295 |

building are obtained by ambient vibration techniques. The vibration periods are: 0.54 s (longitudinal), 0.50 s (transverse) and 0.48 s (torsional).

In Fig 4 the presence of the isolating system is easily identified in the fundamental modal shape of the building.

A three-dimensional linear structural model which reproduced the measured modal shapes and frequencies was implemented in a personal computer. From this, more simplified non linear models with the basic features of the real structure are analyzed in the time domain.

4 ASSUMED GROUND MOTIONS

The building models are subjected to seven accelerograms (see Table 1) scaled to 100 years return period, consistent with a seismic hazard study of the zone were the building is located (Zone II of Mexico City). The maximum acceleration spectral ordinates of the recorded motions are scaled to reach 0.23 of gravity (g). The resulting scale factor is applied to the acceleration records.

The magnitudes ($M_s$) corresponding to the selected ground motions are $M_s$ = 6.4 for record No 1; $M_s$ = 8.1 for records Nos 2, 3, 4 and 5; and $M_s$ = 7.5 for records No 6 and 7.

At the zone of interest the dominant acceleration periods are about 1 to 2 s.

## 5 SHEAR BUILDING IDEALIZATION

First, a preliminary analysis with shear building models is made. The structure is assumed to have linear behavior, except between the basement and the upper-structure where the isolating-dissipating system is placed. At this level bilinear inelastic behavior takes place.

The required lateral resistance of the isolating system is determined by the wind force conditions of the site, and its stiffness by the characteristics of the dissipating device assumed in this study.

The dissipating device consists of a segment of commercial steel plate bent to a U shape. This device has been extensively analyzed in the laboratory of the Institute of Engineering of the National University of Mexico (Aguirre, 1992). Its highly stable energy dissipating capacity is produced by rolling bending, similar to that of caterpillar belts in tractors. Its force-displacement relationship is hysteretic bilinear with post-yield stiffness equal to 5 % of the initial stiffness ($k_2 = 0.05\ k_1$).

Based on the wind force analysis it was decided to include a total of 194 double U hysteretic dampers in the isolated structure.

The story shear forces produced by the scaled ground motions are calculated for the isolated structure as well as for the fixed one. Figure 5 illustrates such forces when the structures are subjected to ground motion No. 1.

The mean value of the reduced shear forces developed on the isolated building are between 45 % and 50% of those corresponding to the fixed structure. A similar result was obtained previously (Ruiz, Esteva and Guerra, 1977).

## 6 FRAME BUILDING IDEALIZATION

A flexible beams frame model with similar dynamic characteristics as those of the shear model just described is also analyzed. In this case, non linear behavior of the upper-structure is designed by assuming that the dynamic base shear is 45 % of its value for the case of a fixed structure (as it is obtained in the previous section of this paper). The fixed structure is designed by using the seismic design spectrum corresponding to the intermediate zone of Mexico City, affected by a reduction factor (Q) which accounts for the ductility demand of the structure. Here a Q factor equal to 3 is adopted. The force-displacement relationship

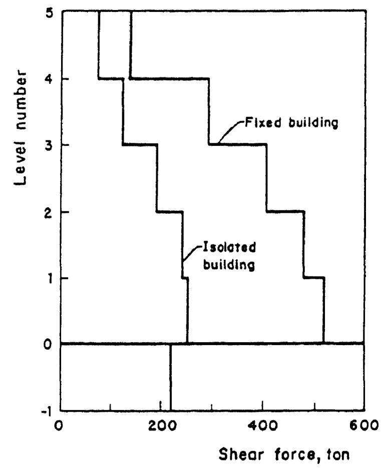


Fig 5 Shear force of fixed and isolated buildings subjected to motion N°1

of the beams is assumed bilinear inelastic with post-yield stiffness equal to 1 % of the initial stiffness.

The seismic response is obtained using the DRAIN-2D computer program. The dynamic behavior of the isolating system as well as of the structural members is taken as non-linear.

The ductility demand for the fixed structure was about 3, as it was supposed in the structural design.

Plastic hinges of both structures (isolated and fixed) are shown in Fig 6. It can be appreciated that the damage is much lower for the isolated building than for the fixed one.

The mean base displacement (upper-structure relative to basement) of the building obtained with the frame model is about 3 cm. The difference observed between the dynamic responses obtained by means of the shear and the frame models can be attributed to the fact that the structural period of the frame model is longer than that of the shear building, and that, for the former, the corresponding ordinates of the acceleration response spectrum are higher than for the shear model.

## 7 PARAMETRIC STUDY

In order to estimate the influence of the bilinear behavior of the isolating-dissipating system, the isolated frame building described in section 6 is analyzed with different assumption about the behavior of that system.

The initial stifness ($k_1$) and the lateral resistance (the latter imposed by wind requirements) are supposed constant, but the post-yielding stiffness ($k_2$) is changed from

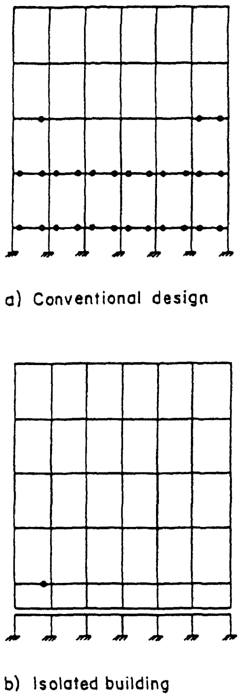


Fig 6 Plastic hinges of buildings subjected to motion N° 1

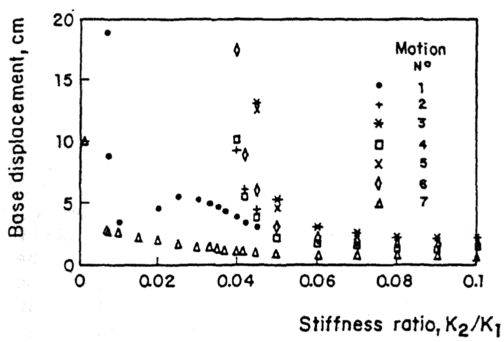


Fig 7 Base displacement of buildings subjected to a family of ground motions

3 % to 10% of $k_1$, that is $k_2 = \alpha k_1$, $.03 \leq \alpha \leq .10$

Results of the upper-structure base displacements, for each of the seven scaled ground motions are shown in Fig 7. There, it can be appreciated that for stiffness ratios lower than 0.05 the building base displacements are substantially increased: for example, for stiffness ratios in the interval $.005 < k_2/k_1 < .04$ the displacements reach values higher than 20 cm. This means that the designer must leave enough space between the isolated structural system and the retaining walls surrounding the structure. It is also noted that the specific characteristics of the ground motions give place to wide discrepancies between the dynamic responses of the system (see for example responses to ground motions Nos. 1 and 3).

These results suggest that the post-yielding stiffness $k_2$ in this structure should be equal or greater than $.05\ k_1$ in order to get reasonable base displacements.

## 8 COST ANALYSIS

An economical study of the building with and without isolating-dissipating system is made. The study takes into account construction costs in Mexico City at the end of november 1991.

The following is a list of the costs of the most relevant concepts associated to the isolating-dissipating system to be place on the building analyzed here.

| Concept | Cost (dollars) |
|---|---|
| Isolating devices (plates and balls) | $ 14,300 |
| Dissipating devices (U shaped) | 18,500 |
| Additional* structure | 61,000 |
| Additional* instalations | 6,500 |
| T o t a l | $ 100,300 |

The stars in the proceeding list correspond to the additional reinforced concrete construction and service instalations that should be placed at the bottom of the isolated structure.

The total unit cost of a traditional structural design (without isolating devices) in Mexico City is about $ 367.00/m². In our case a 5382 m² construction is treated; this means that the total bulding cost is about $ 1'975,194. From here, it is concluded that the cost of the isolated building is increased approximately 5 % with respect to that corresponding to a traditional design. Such percentage becomes lower for important constructions such as hospitals, communication centers, power stations, etc., and also for buildings located on sites where the ground motion dominant period is equal to or smaller than the fundamental period of the building without isolation.

A more detailed cost analysis of the building under study, with and without isolating system, is presented by Sosa (1992).

## 9 CONCLUSIONS

The seismic isolator-disipator systems analyzed here are a good solution for intermediate period structures located on sites subjected to short to intermdiate motion periods.

The hysteretic dissipating device (U shaped steel plate) proposed by Aguirre (1991,1992) shows a satisfactory behavior when installed in isolated structures like the one studied in this paper. The main advantages of this device are: its highly stable cyclic behavior and its low cost.

The lubricated-balls system proposed and built by González-Flores (1964) is a very good option to isolate low buildings founded on hard and intermediate soils. The durability of this system constitutes an advantage which should be taken into account over other isolating solutions.

The shear and frame isolated building models give place to slightly different story shears. Therefore, in order to estimate the reduction in the story shear forces due to the base isolation, the structure can be analyzed in the time domain using a shear building model. However, this model is not recommended for the purpose of estimating the non-linear dynamic response of the upper structure or the building base displacement.

From the parametric study it is concluded that the upper-structure base displacements depend on the ground motion characteristics. This is more noticeable for low stiffness ratios $k_2/k_1$ of the dissipating base system ($0 < k_2/k_1 < .05$). For these ratios base displacements reach in some cases more than 20 cm. This results should be kept in mind when designing building isolating systems.

The inclusion of the isolating-dissipating system in the building analyzed here increases about 5 % the cost with respect to that of the conventional design. Due to the fact that this building is a public school with simple low-cost finishings, this figure can be taken as an upper bound to the values to be excepted in buildings having similar properties.

## 10 ACKNOWLEDGEMENTS

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