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Seismic performance of buildings with energy dissipating systems

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ABSTRACT: We analyze the efficiency of several stiffening and dissipating systems incorporated in typical building models of Mexico City. We compare the frame seismic response with energy dissipating systems against braced frames and frames with prestressing cables. We study the analytical response of a ten storey steel structure considering the soil-structure interaction due to the aceleration recorded at SCT during the 1985 Michoacán earthquake, and a nine storey concrete building subjected to other two records of the Michoacán earthquake. Results show the importance of the devices' yield displacement point in the building response and the strong reduction of the stories' ductility demand in the stiffened frame.

1 INTRODUCTION

The enormous losses of last decade due to earthquakes in the whole world have forced the profession to look for alternative structural systems to modify the design philosophy of existing codes. An attractive system consists in incorporating devices into buildings to improve their energy dissipating capabilities.

The Institute of Engineering of the National Autonomous University of Mexico tested U-shaped steel plates with elastoplastic behavior incorporated into a two storey braced frame under harmonic loading (Chávez and González, 1989). Also with elastoplastic behavior double triangle-shaped steel plates were incorporated into a two storey steel frame and tested at the University of California at Berkeley (Whittaker, 1989).

Due to the large number of buildings to be retroffitted after the 1985 Mexico earthquake a new upgrading technique was developed combining the original structure with prestressing cables as braces (Rioboo, 1989).

These systems were incorporated into models of two typical Mexico City building in order to compare the analytical seismic response.

2 SEISMIC EXCITATION

Mexico City is divided into three principal geotechnical areas. The 1985 Michoacán earthquake was recorded in several seismic stations located on hard, transition and soft soil. We selected E-W components of the TACUBAYA, VIVEROS and SCT records as representative of each soil. Figs 1, 2 and 3 show the accelerograms, their Fourier spectra and their response spectra, respectively, at these locations.

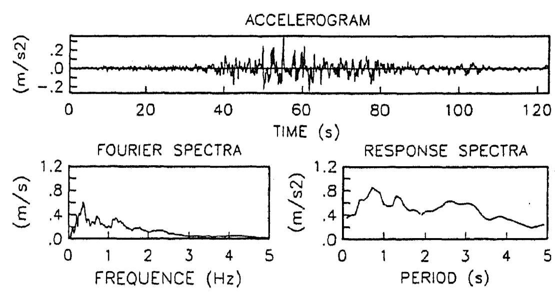

Figure 1. 1985 Mexico earthquake. TACUBAYA record

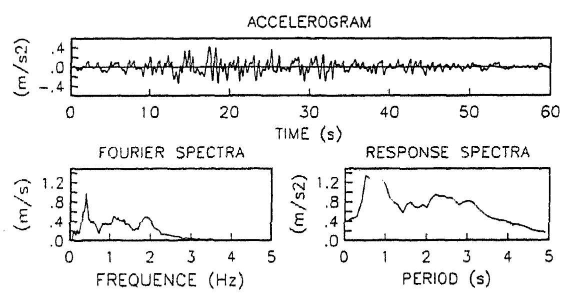

Figure 2. 1985 Mexico earthquake. VIVEROS record

3 STEEL FRAME MODEL

Figure 4 shows the ten storey single bay

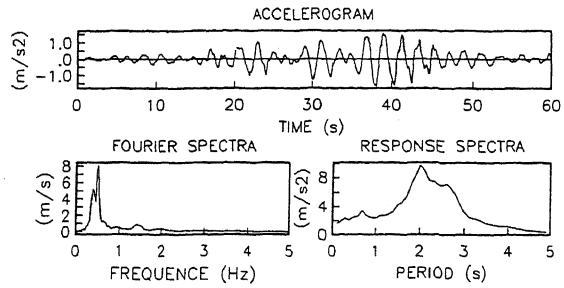

Figure 3. 1985 Mexico earthquake. SCT record

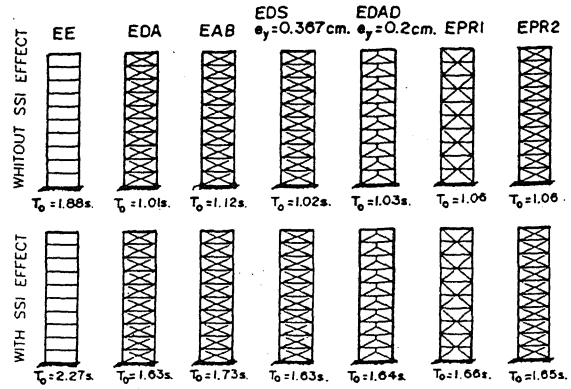

Figure 4. Ten storey single steel bay frame

frame models with their corresponding periods. The structure was previously analyzed by Filiatrault et al (1990) with different energy dissipating devices. The inelastic response analysis was done with the DRAIN program (Kanaan, 1973). The first six models shown do not consider soil-structure interaction, whereas the others do. We incorporated the ADAS, the U-shaped steel plates and the prestressing cables in the structure in order to compare the seismic response. The responses are comparable because of the similar periods. Some models have two periods. The first is the elastic period and the second is obtained after the devices yield. The nomenclature used is,

a) Moment resistant frame (EE)
b) Braced frame (EDA)
c) Base isolated brace frame (EAB)
d) Frame with U-shaped devices (EDS)
e) Frame with ADAS devices (EDAD)
f) Frame with prestressing cables (EPR1 and EPR2)

The model results of EDAD and EDS were found to be quite similar.

Soil-structure interaction (SSI) was considered with elastic supports associated with translation (Kh), vertical displacement (Kv) and rotation (Kϕ) of the foundation. In order to compare with Filiatrault's study, we use the following expressions:

$$Kh=\frac{32\rho V\ R^2(1-\nu)}{(7-8\nu)} \quad (1)$$

$$Kv=\frac{4\rho V^2 R}{(1-\nu)} \quad (2)$$

$$K\phi=\frac{8\rho V^2 R^3}{3(1-\nu)} \quad (3)$$

where ρ is the soil mass density, V the shear wave velocity, ν the Poisson's ratio and R the equivalent foundation radius.

3.1 Displacements and ductility demands

The total displacements, relative displacements and storey ductility demands of the EE, EDA, EDS EDAD and EPR2 models are shown in figs 5 to 9 subjected to the SCT record. The EE model presented many plastic hinges in the beams and there are no strong differences between this model and the model with SSI due to their periods, although the storey ductility demands are the highest of all the models.

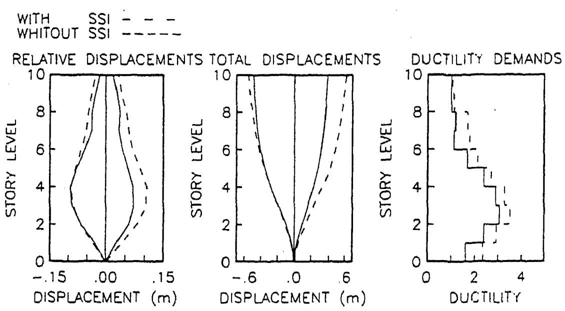

Figure 5. Model EE

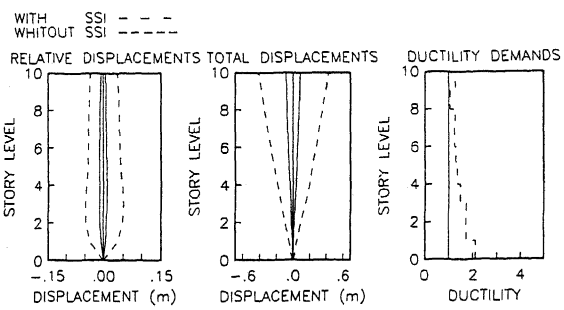

Figure 6. Model EDA

Excluding the EE model, the models remain elastic without considering SSI but they have

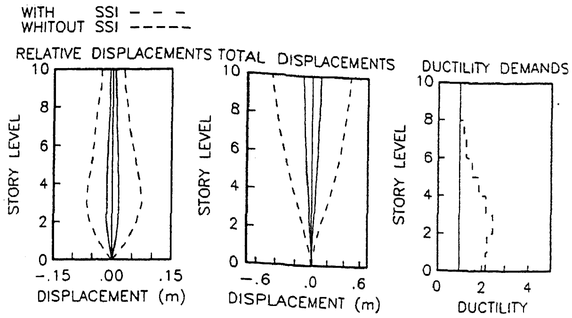

Figure 7. Model EDS

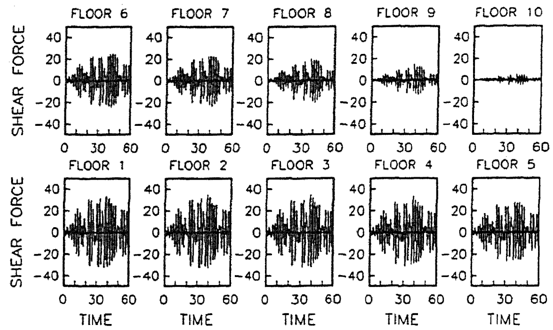

Figure 10. Model EE whit SSI

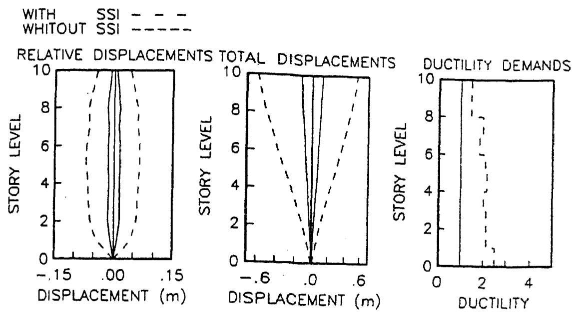

Figure 8. Model EDAD

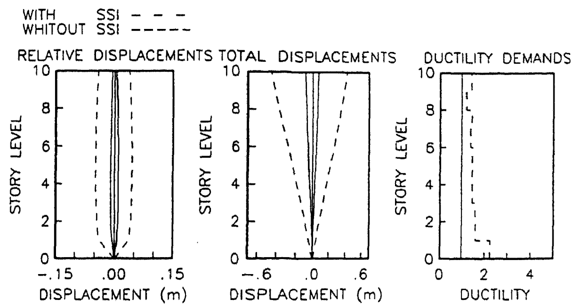

Figure 9. Model EPRE2

larger differences in behavior as compared with the EE model when SSI is considered.

Similar behavior is obtained with the EDA, EDS, EDAD and EPR2 models without SSI. However, there were some differences when SSI was incorporated. The EDA and EPR2 models presented the smallest displacements and similar ductility demands. Comparing the EDS and the EDAD models, the latter had more regular ductility demands along the building height.

The fixed yield point of the U-shaped steel plates manufactured today is probably their main limitation. This can make it difficult, in some cases, to reach the device yield force and hence the structural behavior could be similar to that of a braced frame.

3.2 Shear forces

There are no great differenced in the histories of the storey shear forces of the EE model with and without SSI (fig 10). This behavior can be attributed to the model periods as compared with the SCT response spectra.

The SSI had large influence in the shear forces obtained in the EDA, EDS, EDAD and EPR2 models. Comparing with the EE model, the EDA model without SSI reduced the EE model shear forces and had the highest shear forces of all models with SSI. The EDAD model (similar to EDS model) had larger shear forces as compared with the EE model for both cases but smaller forces than the EDA and EPR2 models. To understand the large shear forces of EDAD and EDS models, we must refer to the dominant period of the groun motion. Although, the periods of the EDAD and EDS models are identical to the period of the maximum response of the spectrum the shear forces are smaller than the forces in the EDA model which can be attributed to the energy dissipation of the devices.

The history of shear forces in the EPR2 model considering SSI is shown in fig 11.

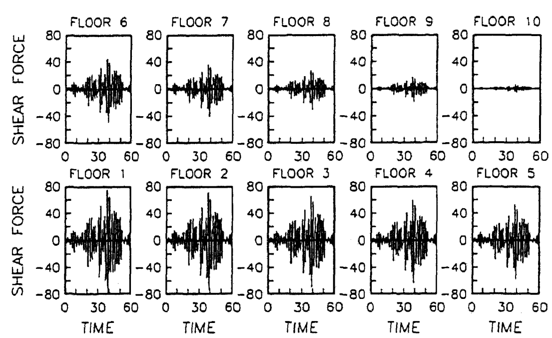

Figure 11. Model EPRE2 With SSI

4 PARAMETRIC STUDY OF A SINGLE DEGREE OF FREEDOM SYSTEM

Observing the foregoing results, there were some periods where the frame behavior were found better than the frame with energy dissipating devices. We studied a one storey single bay frame as a single degree of freedom system with several combinations of frame and device stiffness excited by the SCT record. The period range was 0.5 to 3.0 s. We found unfavorable behavior when the frame periods were between 1.6 and 2.5 s.

Subjecting the system to the TACUBAYA and VIVEROS records (hard and transition soil), we found excellent performance of the frame with devices for all the periods studied.

5 CONCRETE MODEL

The building is a nine storey structure with three bays in one direction and four in the other. The inelastic analysis was made considering planar frames with the DRAIN program. Fig 12 shows the building plan view and elevation. We studied the following structural models,

a) Moment resistant frame (CEE)
b) Braced frame (CEDA)
c) Frame with U-shaped devices (CEDS)
d) Frame with ADAS devices (CEDAD)
e) Frame with prestressing cables(CEPR)

The fundamental periods of the models are shown in table 1.

Table 1. Periods of the concrete models

MODEL	T_o	T_f
CEE	0.836	
CEDA	0.610	
CEDAD	0.560	0.620
CEDS	0.550	0.620
CEPR	0.610	

5.1 Displacements and ductility demands, SCT record

The total and relative displacements were reduced around 50% with the CEDAD model as compared with the CEE model.

A strong reduction was obtained of the CEE model displacements compared with all the other models. Performance of cases b), c) and e) were quite similar due to the elastic behavior of the frame when the stiffening systems were incorporated.

The CEDS model behave quite similar to the CEDA model because of the fixed yield point of the devices. Their behavior was almost elastic so that the frame worked as a braced frame.

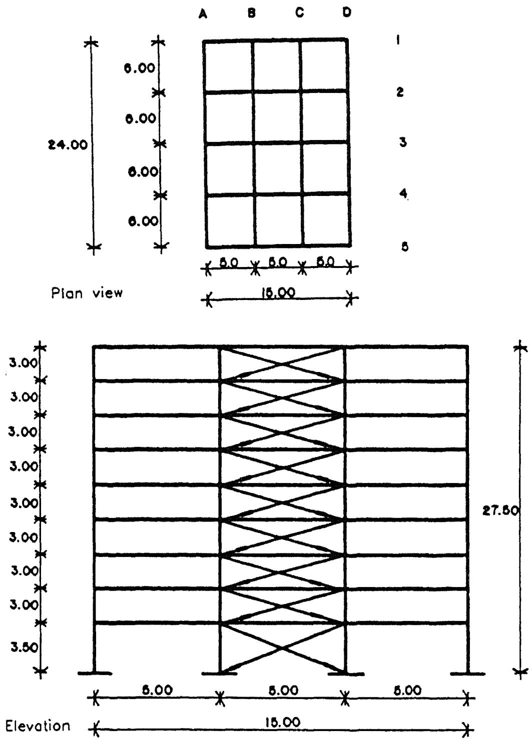

Figure 12. Nine storey concrete structure with three bays

The maximum ductility demand of the CEE model was of the order of 4. This was reduced by a factor of 2 in the CEDAD model. As stated above, the rest of the models behaved elasticaly.

5.2 Shear forces due to SCT record

As expected, the base shear forces were identical for the CEDA and CDS models. They were around 30% greater than the shear forces of the CEE model.

The CEPR model had identical base shear forces of the CEE model and they were slightly grater for the CEDAD model.

5.3 Displacements and ductility demands due to TACUBAYA and VIVEROS records

Because of the small amplitudes of these records, we decided to scale them with the criterion of producing similar number of plastic hinges in the CEE model as when it was excited by the SCT record.

Coincident results were found when the models were subjected to the TACUBAYA and VIVEROS records. Figure 13 shows the displacements of the CEE model. They were reduced around 35% with the CEDA (fig 14) and

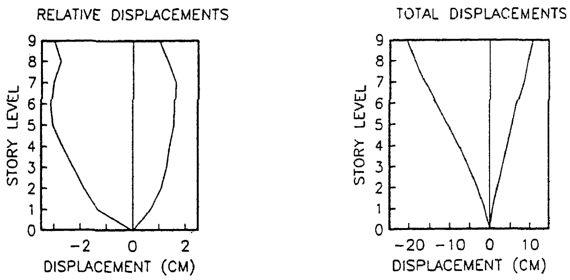

Figure 13. Concrete frame VIVEROS record

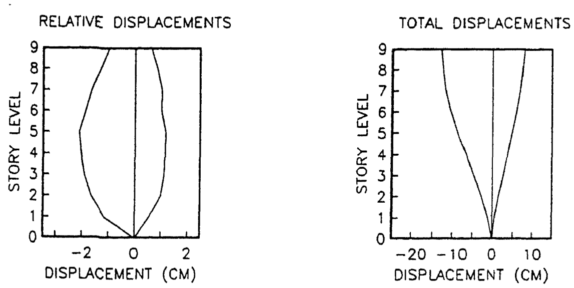

Figure 14. Braced frame VIVEROS record

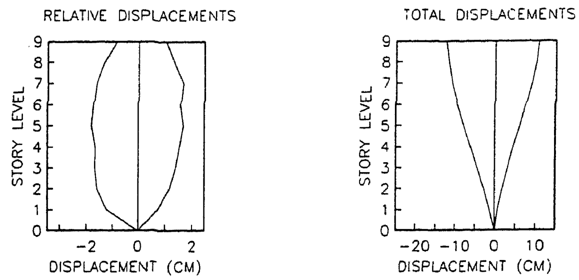

Figure 15. Frame with prestressing cables VIVEROS record

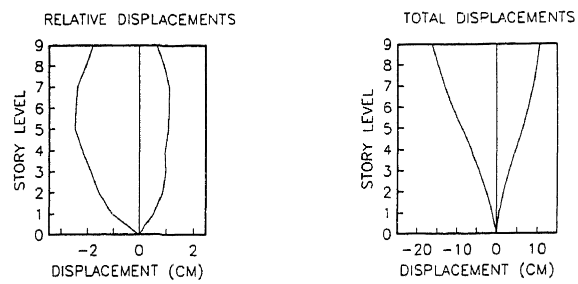

Figure 16. Frame with ADAS devices VIVEROS record

CEPR (fig 15) models and only 20% with the CEDAD (fig 16) model.

The maximum ductility demand found in the CEE model was 9. This was reduced to 4 with the CEDA and CEPR models and to 6 with the CEDAD model.

By plotting the hysteretic behavior of the devices in time intervals, it was found that the dissipated energy is concentrated in a short range. This range was shorter than the SCT record for the TACUBAYA and VIVEROS records.

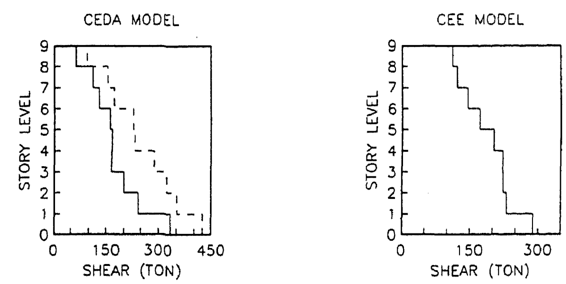

Figure 17. Braced frame VIVEROS record

5.4 Shear forces due to TACUBAYA and VIVEROS records

Figure 17 shows the storey shear forces of the CEDA model. On the left side the total shear forces (broken line) and the frame shear forces (solid line) are shown. The difference between these two lines gives the shear forces corresponding to braces. The right side shows the frame shear forces corresponding to the CEE model in order to compare them with the CEDA model. With the same format, figs 18 and 19 show the shears corresponding to the CEDAD and CEPR models respectively.

The CEDA model undergoes the maximum increment in the shear forces as compared with the CEE model, and the increment in the CEDAD model is practically nil.

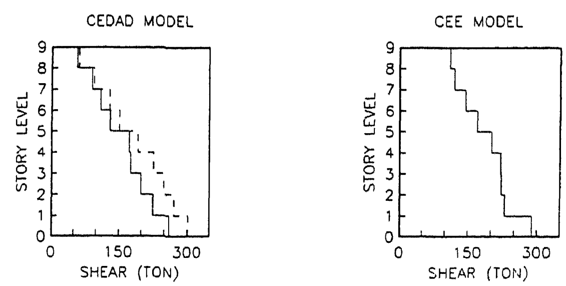

Figure 18. Frame with ADAS devices VIVEROS record

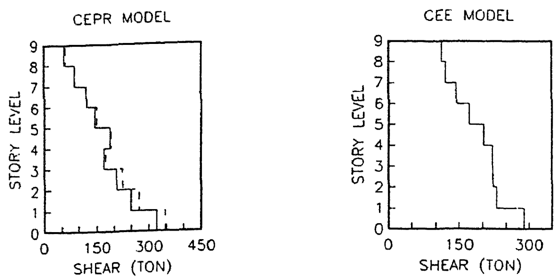

Figure 19. Frame with prestressing cables VIVEROS record

6 SUMMARY AND CONCLUSION

The purpose of this paper has been to determine the seismic response of structures with devices in order to improve the strength and stiffness of moment resistant frames.

There is promise in the use of energy dissipating devices and prestressing cables to reduce the seismic damage in buildings located in Mexico City subjected to earthquakes generated in the Mexican Pacific Coast.

Soil-structure interaction has an important effect on the structural behavior with devices when the buildings fundamental period lies close to the ground prevailing period.

The parametric study of a single degree of freedom system with energy dissipating devices showed that in the Mexico City soft soil is unfavorable to incorporate devices when the period lies between 1.6 and 2.5 s and the prevailing ground period is close to 2.0 s.

The model with prestressing cables had satisfactory behavior for the three records used. It is, however, necessary to study a single degree of freedom system to obtain more general results of these systems.

The very similar shear forces between the original frame and the frame with prestressing cables or energy dissipating devices is the principal advantage of these systems over other stiffening systems.

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