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SEISMIC BEHAVIOUR OF STRUCTURES WITH ENERGY DISSIPATING SYSTEMS IN MEXICO

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SUMMARY

Energy dissipating devices have been used extensively in many countries of the world to reduce damages produced by earthquakes. The paper studies the performance of a single degree of freedom system with energy dissipators of elastoplastic behaviour. The system was subjected to the E-W component of the 1985 Michoacan Earthquake registered at the SCT accelerographic station. Initially, a parametric study was carried out incorporating a wide range of the most significant parameters that contribute to the inelastic seismic response. Strength and stiffness characteristics of the structure and dissipators are of primary interest in this study. It is quantified the contribution in the response of the bare frame period, period of the structure with dissipators, yield displacements of the structure and devices, lateral stiffness of the structure, braces and devices. Particular attention is devoted to determine limit states of behaviour, focusing on ductility demands of the frame and dissipators. Finally, it is shown that there is a specific range of periods where the addition of dissipators is attractive in Mexico. Results can be used for the preliminary selection of the mechanical and geometrical properties of structures with energy dissipating devices of elastoplastic behaviour.

INTRODUCTION

Because of the enormous human and economic losses due to earthquake events, there has been done much analytical and experimental work in the last years directed towards obtaining a better understanding of the behaviour of structures with energy dissipating devices. There are currently a great variety of devices produced with several mechanical characteristics and different behaviours. The materials most frequently used to manufacture the devices are steel and lead, and many of them have elastoplastic behaviour. These devices have in common the high number of load cycles supported without almost any stiffness or strength degradation.

The Institute of Engineering of the National University of Mexico manufactured a U-shape device with elastoplastic behaviour (Aguirre and Sánchez, 1989 y 1990) that was incorporated in a two-storey building tested on a shaking table (Chávez and González, 1989). According to results, this device is a promising system to improve the seismic behaviour of structures located on the soft soils of the valley of Mexico.

Whittaker et al, 1989 and Alonso, 1989 tested a steel X-shaped device called ADAS (Added Damping and Stiffness) in the University of California at Berkeley. The plates have elastoplastic behaviour with very stable hysteretic loops. ADAS devices have been incorporated to retrofit some buildings in Mexico City (Martínez, 1990). The performance of these structures has not been verified yet, due to the lack of strong earthquakes after the device implementation.

Due to the high seismic activity in Mexico, it is quite important to increase the number of studies, regarding to determine the applicability of energy dissipating devices in reducing building damages. These studies should be conducted considering the most common structural systems built in Mexico.

The study addresses with the selection of the characteristics of energy dissipators to be used in buildings located

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on soft soils in Mexico City. Initially, a parametric analysis of a single degree of freedom system, subjected to a seismic record registered during the 1985 earthquake in Mexico City, has been performed. Thus, base on these results, the best parameters for the analysis of several degree of freedom systems subjected to four records registered on the lake zone of the Valley of Mexico were chosen. This paper describes the outcomes of the parametric study.

PARAMETRIC STUDY OF A ONE DEGREE OF FREEDOM SYSTEM

Model description

The purpose of the analysis of a simple system is twofold: to determine the contribution of each parameter on the seismic response and to reduce the range variation of the values for the analysis of the multi-degree of freedom models. The model analysed (fig 1) is a one story bare frame with a dissipator located at the middle of the bay and connected to the base through chevron braces. Lateral stiffness of the frame, braces and dissipator are named Km, Kc and Kd, respectively.

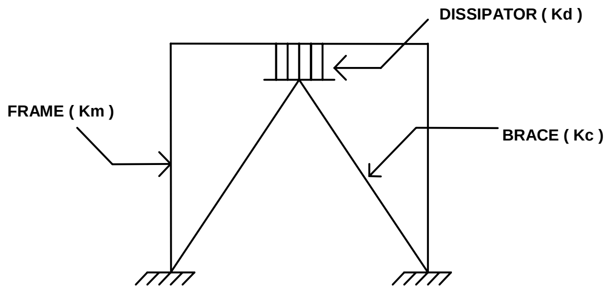


Fig 1: One degree of freedom system

Seismic performance assessment is determined for three models: bare frame (BAF model), frame with dissipator (DIF model) and braced frame (BRF model, fig 2).

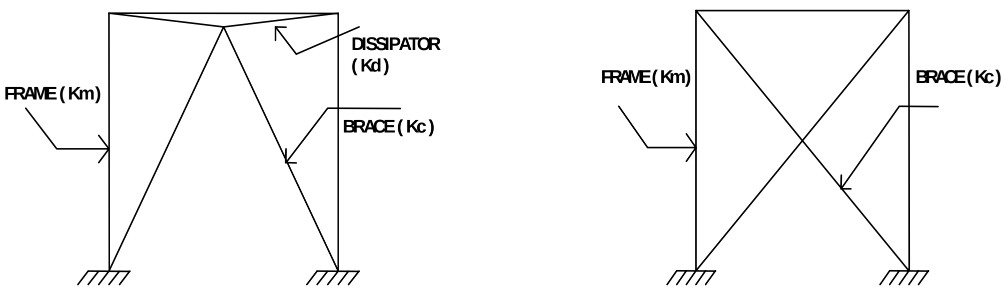


Fig 2: Analytical frame models

Lateral stiffness of each model depends on the frame, braced and device stiffness as shown in fig 3. In this figure, K_T is the total lateral stiffness, K_M the frame stiffness, Kc the braced stiffness of the model with dissipators, Kd the device stiffness, K_{CD} the braced-device stiffness, Δ_{YM} the yield displacement of the bare frame and Δ_{YD} the yield displacement of the device.

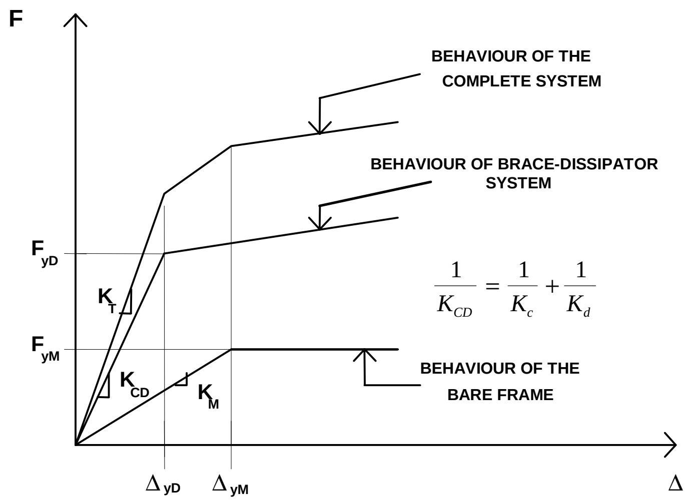


Fig 3: Lateral behaviour of the bare frame with dissipators

Parameters of the analysis

The following variables (table 1) were considered for the inelastic analysis of the models. Range values of the parameters were chosen to be representative of most typical buildings in Mexico.

Table 1: Parameters for the inelastic analysis

PARAMETERS	RANGE VALUES
T	0.5,1.0,1.5,2.0,2.5 Y 3.0 sec
$\mathbf{K_{CD}/ K_M}$	1.0,1.5,2.0,3.0 Y 5.0
$\mathbf{K_C/ K_D}$	0.5,1.0,1.5,2.0,3.0, Y 5.0
$\mathbf{\Delta_{YM}/\Delta_{YD}}$	0.5,1.0,1.5,2.0,3.0,4.0,5.0 Y 10.0

Where T is the period of the bare frame and K_{CD} is the brace-device lateral stiffness of the DIF model and the brace stiffness of the BRF model. Periods were modified changing the mass of the system.

Parametric study

Structural models were subjected to the east-west component of the 1985 Michoacan earthquake registered at the SCT station in Mexico City (SCT-85). According to the response spectra, the record presents a dominant period (Ts) of two seconds. Structural elements are assumed to behave elastoplastically and for each period, lateral stiffness of the braces (BRF model) has been chosen to be the same of the brace-device lateral stiffness (DIF model), in order to make comparable both models. Inelastic analysis were carried out using DRAIN2DX program (Prakash et al, 1992).

The overall response was studied establishing the following limit states and finding the relation K_{CD}/K_M, K_C/K_D, and Δ_{YM}/Δ_{YD} to fulfill the following limits.

a. Elastic behaviour (frame, braces and devices)

b. Frame ductility demands of 1.0, 1.5, 2.0 and 3.0

c. Dissipator ductility demands of 5,10 and 15

Results

Inelastic analysis using the above parameters and the three models aforementioned were carried out. The demands imposed by the excitation were obtained as a function of the period of the bare frame (T). For each analysis, it was calculated maximum storey displacements, storey ductility demands and ductility demands of dissipators, presented in graphs that can be consulted in Jara, 1998. Trend of the behaviour is outlined in the next paragraphs.

When the period of the bare frame is located in the ascendant curve of the response spectra ($T/T_s<1$), interstory frame displacements decrease with the increment of the relation K_{CD}/K_M. Moreover, there is a small contribution of the relation K_C/K_D in this range of periods. Ductility demands on dissipators are strongly reduced with the increment of the stiffness relation until $K_{CD}/K_M=3$; for greater values there is not an important response reduction. The general trend shows increments of ductility demands in dissipators with the rise of the relation K_C/K_D. Small values of K_{CD}/K_M and large values of the Δ_{YM}/Δ_{YD} relation produce also large ductility demands. As the period of the bare frame approaches the dominant period of the seismic record, the Δ_{YM}/Δ_{YD} relation must be reduced to constraint the dissipator ductility demands.

It is meaningful to mention the behaviour for $T/T_s=1$. For this period, the frame can not always remain elastic in the entire range of the parameters studied. Additionally, ductility demands of the frame are less sensitive to the K_C/K_D relation, when K_{CD}/K_M is greater than 3.0.

As regards to $T/T_s>1$, there is strong dependence of ductility demands with yield displacements. A small yield displacement of dissipators, as compared with yield displacement of the frame, implies increase of ductility demands. This is a consequence of the shape of the response spectra that has an important amplitude reduction after $T/T_s=1$.

Limit state of elastic behaviour of the frame and dissipators

Previous results assess the contribution of each variable in the response of the system. However, to resume the behaviour, the following graphs of limit states are presented. Values of Δ_{YM}/Δ_{YD} were calculated for each $T_{c/d}$ (period of the system with dissipators) to allow a desired behaviour. Fig 4 shows a plot of $T_{c/d}$ versus Δ_{YM}/Δ_{YD} values for the elastic behaviour of the frame and dissipators when T=0.5 sec ($T/T_s=0.25$), the area under the line represents the zone where this limit state is accomplished. Dashed line corresponds to the trend behaviour of period values not analysed. The area decreases with the increment of the $T_{c/d}$ period, meaning that it is possible to use greater values of Δ_{YM}/Δ_{YD} while the K_{CD}/K_M relation is increased. There are not important ductility demands because of the short period of the system.

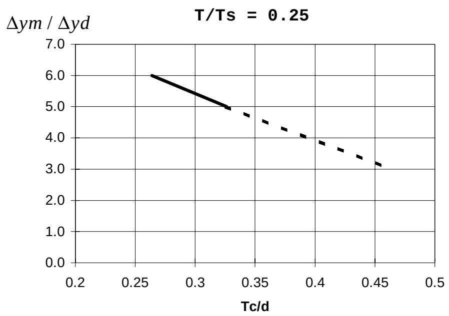


Fig 4: Elastic limit state for T=0.5 sec

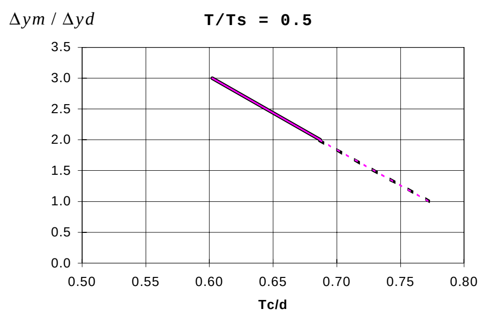
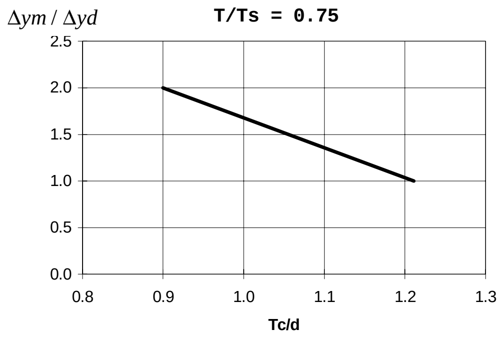


Fig 5: Elastic limit state for T=1.0 sec

As shown in fig 5, there is a reduction of the surface of possible values for elastic limit state when $T/T_s=0.50$ (T=1.0 sec). Now, the maximum value of the Δ_{YM}/Δ_{YD} relation is 3.0, and, in this case, the stiffness of the frame must be increased to reduce the period of the bare frame from 1.0 sec to 0.6 sec.

As expected, the response increases with the period of T=1.5 sec (T/T_s = 0.75), reducing the range of Δ_{YM}/Δ_{YD} values to fulfill this limit state. In this case, to avoid the inelastic behaviour, Δ_{YM}/Δ_{YD} must be less than 2.0 (fig 6).



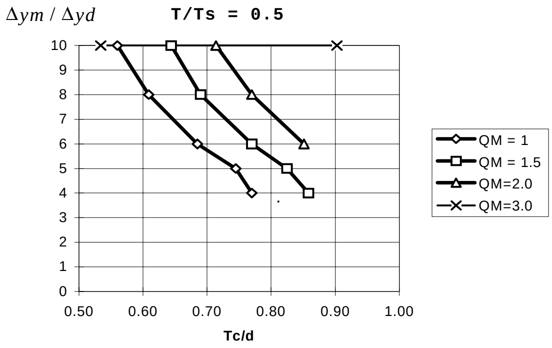


Fig 6: Elastic limit state for T=1.5 sec

Fig 7: Frame ductility limit state for T=1.0 sec

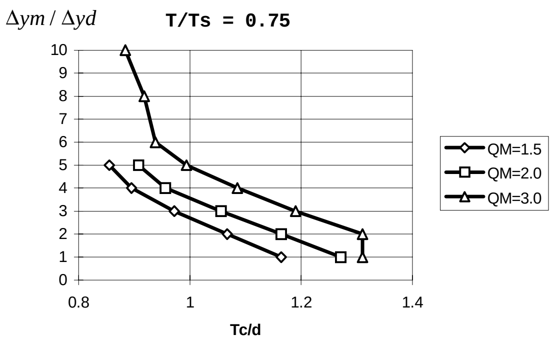
Periods of the bare frame greater than 1.5 sec produce always inelastic behaviour of the system, indicating the boundary of this limit state. However, it must be considered that structures with dissipators are expected to have an important dissipation through the inelastic behaviour of the devices. Because of that, these results are only obtained for completeness of the study.

Limit state of ductility demands on the frame

This limit state is particularly important taking into consideration the structures with limited ductility capacity that must observe the requirements of a new code regulation. The following figures show the range values of the periods and yield displacements of the model with dissipators for attaining ductility demands on the frame of Q_M=1.0,1.5,2.0 and 3.0. Three models were selected to have the same bare frame period of the first mode of vibration associated to the multi-degree of freedom structures studied in Jara, 1998 (T=1.0, 1.87 and 2.92 sec).

The frame with T=0.5 sec (T/T_s=0.25) has an elastic behaviour in the entire range of variables studied, even for the maximum yield relation analysed. Increasing the period of the bare frame to 1.0 sec (T/T_s=0.50), there are incursions of the frame elements in the inelastic range, according to the curves shown in fig 7. However, the ductility demand of the frame does not exceed the value of 3.0. Elastic behaviour is expected when Tc/d>0.55 and the relation Δ_{YM}/Δ_{YD} is greater than 4.0 but less than 10.0 (fig 7).

When the frame period (T=1.5 sec) is close to the dominant period of the seismic record (T/T_s=0.75), ductility demands are always greater than 1.0 (fig 8). For periods of the system with dissipators ($T_{c/d}$) not greater than 1.16 sec, it is always possible to have maximum ductility demands of 1.5. Nevertheless, for greater values, ductility demands are at least of 2.0 and the area below the curves are dramatically reduced. For small stiffness increment of the bare frame is prudent to use Δ_{YM}/Δ_{YD} not greater than 5.0.



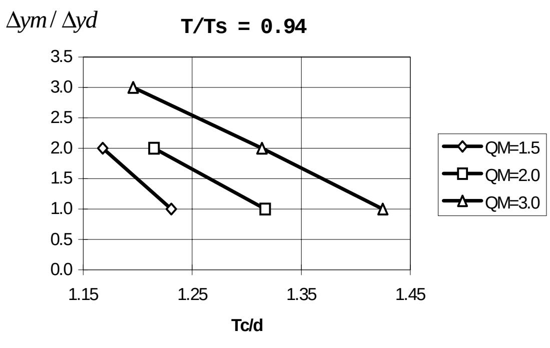
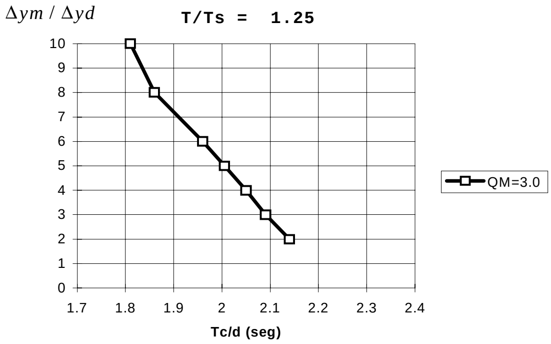


Fig 8: Frame ductility limit state for T=1.5 sec

Fig 9: Frame ductility limit state for T=1.87 sec

The same trend is obtained for the system with period of T=1.87 sec. (T/T_s=0.94). Though, the Δ_{YM}/Δ_{YD} relation that can be used to satisfy the limit states established, is strongly reduced (fig 9). This is understandable considering the proximity of the frame period to the maximum amplitude of the response spectra. Ductility demands lower than 3.0 have been obtained when the relation Δ_{YM}/Δ_{YD} is inferior of 3.0. The lower limit of the ductility demand (1.5) can only be achieved if the original period (1.87 sec) is reduced to the range of 1.17 sec to 1.23 sec, and the Δ_{YM}/Δ_{YD} relation is limited to values not greater than 2.0.

The subsequent system studied (T=2.5 sec) is located on the descendent curve of the response spectra. Incorporating the devices, the period is reduced carrying on the frame to larger responses and generating always ductility demands greater than 2.0 (fig 10). With increments of the period from 1.8 to 2.15 sec, the relation Δ_{YM}/Δ_{YD} must be reduced from 10 to 2, in order to avoid ductility demands greater than 3.0. Based on figures 9 and 10, it must be emphasised the strong dependence of the behaviour on the dynamical properties of the stiffened structure and on the strength properties. This is particularly important when the structure is close to the maximum amplification zone of the response spectra.



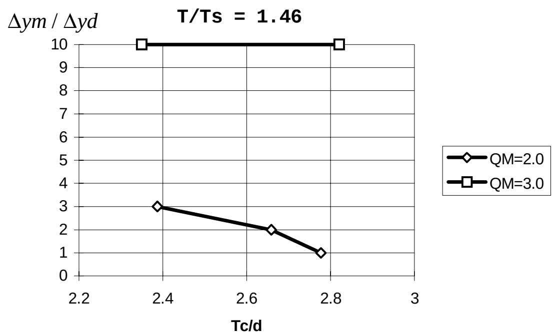
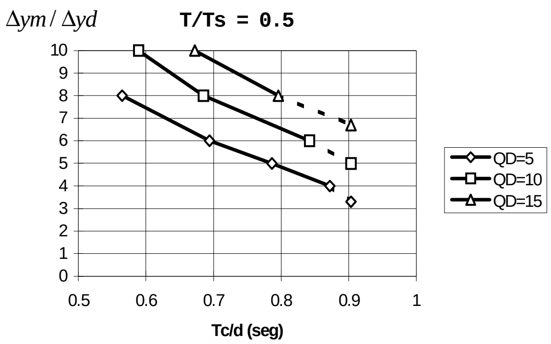


Fig 10: Frame ductility limit state for T=2.5 sec **Fig 11: Frame ductility limit state for T=2.92 sec**

It was anticipated that the structure behaves better when the period of the bare frame increases to 2.92 sec. (because of the response spectra shape). Now, it is also possible to have ductility demands of 2.0 when the yield displacement relation lies between 1.0 and 3.0, and the period of the structure with devices is located between 2.4 and 2.8 sec (fig 11). As shown, even for the maximum Δ_{YM}/Δ_{YD} relation, ductility demands not exceed of 3.0

Limit state of ductility demands on dissipators

According to the elastoplastic devices currently manufactured, three limit states for the ductility demands on dissipators were chosen, Q_D=5, 10 and 15. Fig 12 presents the response of dissipators for T/T_s=0.5. Due to the location of the period in the response spectra, large demands are not expected, so there are several combinations of parameters for the desired behaviour. The area under the curves enlarges with the stiffness increase of the frame, reflecting the possibility of using larger Δ_{YM}/Δ_{YD} values, combined with shorter periods.



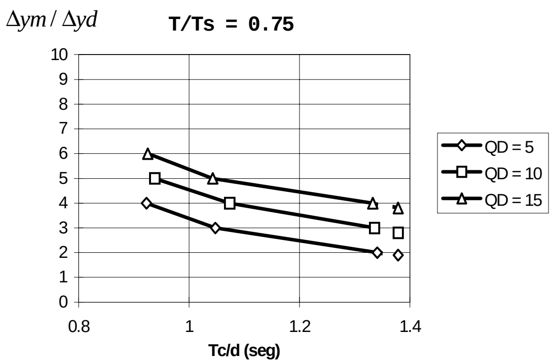
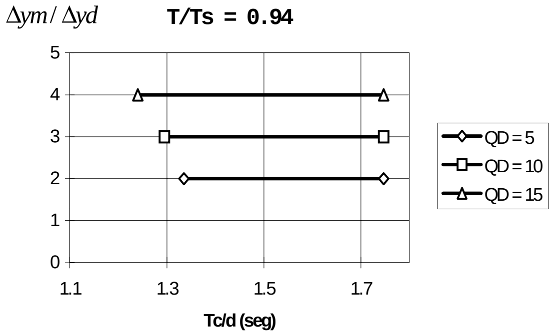


Fig 12: Dissipator ductility limit state for T=1.0 sec **Fig 13: Dissipator ductility limit state for T=1.5 sec**

Similar behaviour is observed for the bare frame with a period of 1.5 sec (T/T_s=0.75). It reduces the range of the parameters for attaining the pre-established limit states (fig 13). Therefore, the yield displacement relation must be reduced to a maximum of 6.0 if the ductility demands on dissipators is to be maintained below 15.0. Thus, attention must be paid to yield displacements because of the high sensitive behaviour to this variable.

The high energy content of the record near of 2.0 sec, is reflected in the behaviour of the system with T=1.87 sec (T/Ts=0.94). Δ_{YM}/Δ_{YD} maximum values must be reduced to 4.0 (fig 14). It is remarkable the reduction of the period ranges for each limit state. Low ductility demands are accomplished small period range. In this case, to retain ductility demands on dissipators below 5.0, 10.0 and 15.0, yield displacement relations (between the frame and dissipators) of 2.0, 3.0 and 4.0 must be chosen, respectively.



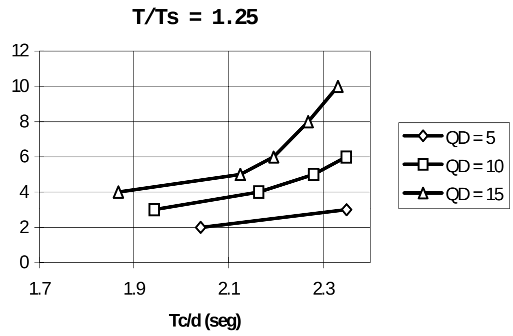


Fig 14: Dissipator ductility limit state for T=1.87 sec **Fig 15: Dissipator ductility limit state for T=2.5 sec**

Because of the lower slope of the descendent curve in the response spectra, as compared with the ascendant one, the values of yield displacement relations for achieving certain limit state are expanded, as shown in fig 15. Notable is the inversion of the curves (descending with the period reduction) due to larger response associated to the stiffness increment of the structure.

CONCLUSIONS

1. Mid-rise buildings located on soft soil were severely damaged during the 1985 Michoacan earthquake in Mexico City. Due to the high energy content of the record near of 2.0 sec, low and high rise buildings had a satisfactory behaviour. This paper presents some results of the analytical study of structures with energy dissipators of elastoplastic behaviour, for a wide range of periods, considering the main variables that contribute to the seismic response. According to results, inelastic behaviour is expected in structures located on soft soil when their fundamental period is close to the dominant period of the record regardless of the characteristics of dissipators used.

2. To avoid excessive ductility demands in buildings with a fundamental period close to the period of maximum amplitude of the response spectra, interstory yield displacements must lay between one and three times the yield displacement of dissipators. The expected behaviour is also strongly dependent on the additional stiffness added by the brace-dissipator system.

3. The great importance of the story stiffness/brace dissipator-stiffness relation is showed. It is also mentioned the need to carefully choose the interstory yield displacements and the yield displacements of dissipators. It must be emphasised that a correct parameter selection is the only way to produce suitable behaviour of the structural system.

4. Considering that general behaviour of regular mid-rise structures can be predicted with equivalent one degree of freedom systems, previous results could be used for the preliminary selection of the mechanical and geometrical properties of dissipators.

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