EFFECTIVENESS OF ISOLATION DEVICES ON THE BUILDING RESPONSE TO EARTHQUAKE LOADING

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SUMMARY

The effectiveness of isolation devices located at the base of buildings is studied. The building is modeled as a 1 DOF oscillator, with non-linear load-lateral displacement characteristics. The isolation devices are modelled as a second degree of freedom, with non-linear response characteristics too. Furthermore, it is assumed that the total lateral displacement of the base is limited to a given value by means of an elastic buffer.

Two sets of artificially generated earthquake records are used, comprising 10 records each. The first set represents a likely event with a return period of 50 years occurring near Santiago. The second set is for an earthquake with epicenter at about 400 km, near Concepción.

The results show that by means of an appropiated selection of the isolation system parameters, the structural response can be limited to the elastic range.

INTRODUCTION

Up to present, few theoretical work has been done in the area of earthquake isolation. A summary of the main contributions is contained in reference 1. This work deals with the study of the effect of the different parameters that define an isolation system located at the base of a building. How the isolation devices can be built up in practice is not discussed here. Nevertheless, due consideration is taken of the physical feasibility of the parameter values that define both the structure and the isolation system.

The model used is summarized in figure 1. The system response is obtained assuming linear variation of the ground acceleration between integration points. Then, exact integration formulae are used between points. In the 2 DOF system, modal decomposition is used inside each integration interval. The initial conditions in each step are the displacement and velocity at the end of the previous step.

The study is carried out by means of simulation, using 2 different sets of 10 earthquake each. They represent earthquakes occurring in Santiago with a return period of 50 years. The first set corresponds to an epicentral distance of about 100 km from the site. The second, to an epicentral distance of 400 km. The $\alpha\beta\gamma$ method is used in the earthquake generation (see references 2 and 3).

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RESPONSE OF A 1 DOF BILINEAR OSCILLATOR

The theory used to compute the response of the 1 DOF model was taken from reference 4. The integration procedure supposes a linear variation of the ground acceleration in each time interval. The displacement and the velocity at point i+1 are given as functions of the displacement and the velocity at point i and the modified ground accelerations at points i and i+1,

$$\begin{Bmatrix} u_{i+1} \\ \dot{u}_{i+1} \end{Bmatrix} = \begin{bmatrix} A(\omega,\beta,\Delta t_i) \end{bmatrix} \begin{Bmatrix} u_i \\ \dot{u}_i \end{Bmatrix} + \begin{bmatrix} B(\omega,\beta,\Delta t_i) \end{bmatrix} \begin{Bmatrix} \bar{a}_i \\ \bar{a}_{i+1} \end{Bmatrix} \qquad (1)$$

where

$$\bar{a}_i = a_i - \omega^2 s \quad ; \quad \bar{a}_{i+1} = a_{i+1} - \omega^2 s$$

ω = angular natural frequency of the oscillator
β = % of critical damping
Δt_i = $t_{i+1} - t_i$
s = set of the oscillator
$[A]$ = transfer matrix
$[B]$ = matrix that gives the ground acceleration contribution

RESPONSE OF A 2 DOF BILINEAR MODEL

The model is shown in figure 1. The first oscillator represents the base isolation system and the second the structure. It is assumed that the structure has a bilinear behaviour, with viscous damping. The base system is also bilinear, and elastic buffers have been added in order to limit the lateral displacements.

The response is obtained by means of step by step modal analysis. In each step, the following parameters are defined

$$\omega_1 = \sqrt{k_1/(m_1 + m_2)} \quad ; \quad \omega_2 = \sqrt{k_2/m_2}$$

$$\beta_1 = c_1/(2\omega_1(m_1 + m_2) \quad ; \quad \beta_2 = c_2/(2\omega_2\ m_2)$$

$$\mu = (m_1 + m_2)/m_2$$

Then, the equations of motion are,

$$\begin{bmatrix} \mu & 1 \\ 1 & 1 \end{bmatrix} \begin{Bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{Bmatrix} + \begin{bmatrix} 2\beta_1\omega_1\mu & 0 \\ 0 & 2\beta_2\omega_2 \end{bmatrix} \begin{Bmatrix} \dot{u}_1 \\ \dot{u}_2 \end{Bmatrix} + \begin{bmatrix} \mu\omega_1^2 & 0 \\ 0 & \omega_2^2 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = -\ddot{u}_g \begin{Bmatrix} \mu \\ 1 \end{Bmatrix} + \begin{Bmatrix} \mu\omega_1^2 s_1 \\ \omega_2^2\ s_2 \end{Bmatrix} \qquad (2)$$

In terms of the ratio $r_1 = \omega_1/\omega_2$, the relative natural frequencies are given by,

$$(r_I^2, r_{II}^2) = \frac{1}{2(\mu-1)} \left[\mu(r_1^2 + 1) \mp \sqrt{\mu^2(r_1^2 - 1)^2 + 4\mu r_1^2} \right] \qquad (3)$$

The modal shapes are as follows,

$$[\phi] = \begin{bmatrix} 1/r_I^2 - 1 & 1/r_{II}^2 - 1 \\ 1 & 1 \end{bmatrix} \tag{4}$$

The uncoupled equation are,

$$\ddot{y}_j + 2\omega_j\beta_j\dot{y}_j + \omega_j^2 y_j = -\Gamma_j\,\ddot{u}_g + A_{j1}\,S_1 + A_{j2}\,S_2, \qquad j = 1,2 \tag{5}$$

where

$$\Gamma_1 = \frac{(1/r_I^2 - 1)\mu + 1}{\mu(1/r_I^2 - 1)^2 + 2(1/r_I^2 - 1) + 1} \quad ; \quad \Gamma_2 = -\Gamma_1$$

$$A_{11} = \omega_2^2\mu r_1^2(1/r_I^2 - 1)/\left[\mu(1/r_I^2 - 1)^2 + 2(1/r_I^2 - 1) + 1\right]$$

$$A_{12} = \omega_2^2/\left[\mu(1/r_I^2 - 1)^2 + 2(1/r_I^2 - 1) + 1\right]$$

$$A_{21} = \omega_2^2\mu r_1^2(1/r_{II}^2 - 1)/\left[\mu(1/r_{II}^2 - 1)^2 + 2(1/r_{II}^2 - 1) + 1\right]$$

$$A_{22} = \omega_2^2/\left[\mu(1/r_{II}^2 - 1)^2 + 2(1/r_{II}^2 - 1) + 1\right]$$

The displacements are then obtained from

$$\begin{aligned} u_1 &= (1/r_I^2 - 1)y_1 + (1/r_{II}^2 - 1)y_2 \\ u_2 &= y_1 + y_2 \end{aligned} \tag{6}$$

BUFFERS

Buffers are considered between the base and the ground, as shown in figure 1. When the lateral displacement is equal to plus or minus a given value, an elastic shock against the buffer is assumed, with a restitutive coefficient λ

DAMPING

If damping is defined as the percentage of deformation energy dissipated during the motion, it can be shown that the percentage of critical damping per mode can be expressed as follows,

$$\beta^i = \frac{\sum_j \beta_j\,\omega_j^2(\phi_j^i)^2}{\sum_j \omega_j^2\,(\phi_j^i)^2} = \text{critical damping in mode } i \tag{7}$$

In the present case,

$$\beta^{I} = \left[\beta_1\omega_1^2(1/r_I^2 - 1)^2 + \beta_2\omega_2^2\right] \Big/ \left[\omega_1^2(1/r_I^2 - 1)^2 + \omega_2^2\right]$$

$$\beta^{II} = \left[\beta_1\omega_1^2(1/r_{II}^2 - 1)^2 + \beta_2\omega_2^2\right] \Big/ \left[\omega_1^2(1/r_{II}^2 - 1)^2 + \omega_2^2\right] \tag{8}$$

SIMULATED EARTHQUAKE RECORDS

Probable earthquakes occurring in Santiago, Chile, are considered in this work. Two types of earthquakes are assumed, both with a return period of 50 years. The first set consists of 10 simulated records with epicenter at Valparaíso, some 100 km. West from Santiago. Its focal mechanism corresponds to a sliding motion of the Nazca plate under the South American plate. The second set of 10 records belongs to simulated earthquakes with epicenter at Concepción, 400 km to the South of Santiago. The average earthquake characteristics are as follows.

Earthquake	Duration	Av.Peack Acc.	Nr.of zero crossing	Nr.of maxima	Δt
Valparaíso	120 sec	0.145 g.	1187	763	0.02 sec.
Concepción	120 sec.	0.044 g.	374	194	0.02 sec.

DUCTILITY REQUIREMENTS

In order to compute the ductility required by a structure to support the earthquake motions defined above, a yield level equal to the force defined by the SEAOC code was assumed. The ductility requirements of a 1 DOF structure for the 2 sets of earthquake records were computed. The average ductility ratio and the average plus and minus two times the stardard deviation are plotted in figure 2.

EFFECT OF ISOLATION DEVICES

A parametric study of the response reduction produced by an isolation system is, in general, quite difficult, due to the amount of different parameters involved. Nevertheless, the range of possible values for most of the variables is limited in practice. The following values were assumed in the cases considered: μ = 1.3, $\alpha_1 = \alpha_2$ = 0.2, β_1 = 0.10, β_2 = 0.05, y_{st}/y_{base} = 0.5, and d = 5 cm. They were selected based on results obtained for different cases and on practical considerations. The structural ductility requirements, as a function of the frequency ratio ω_1/ω_2, are plotted for diferent structural natural periods in figures 3 to 6.

CONCLUDING REMARKS

The main purpose of this work has been the exploration of how much reduction in the structural ductility requirements can be obtained by means of adequate selection of the parameters defining the isolation system. In all cases considered, the ductility requirement could be reduced to less than one, i.e., the structure remains in the elastic range. In order to get that result, the required base ductility has to be quite large sometimes. Its magnitude can be controlled by the inclusion of a buffer at a given distance.

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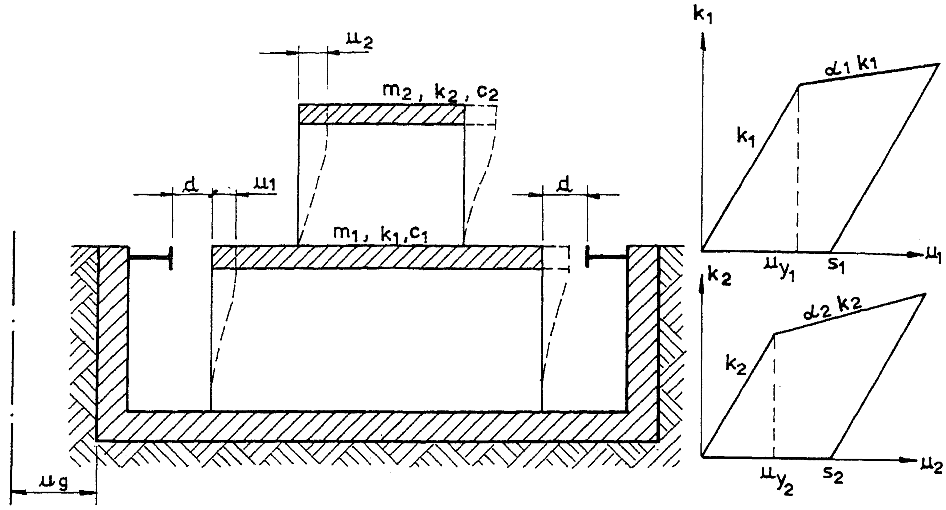

Fig. 1 2 D.O.F. MODEL AND STIFFNESS CHARACTERISTICS.

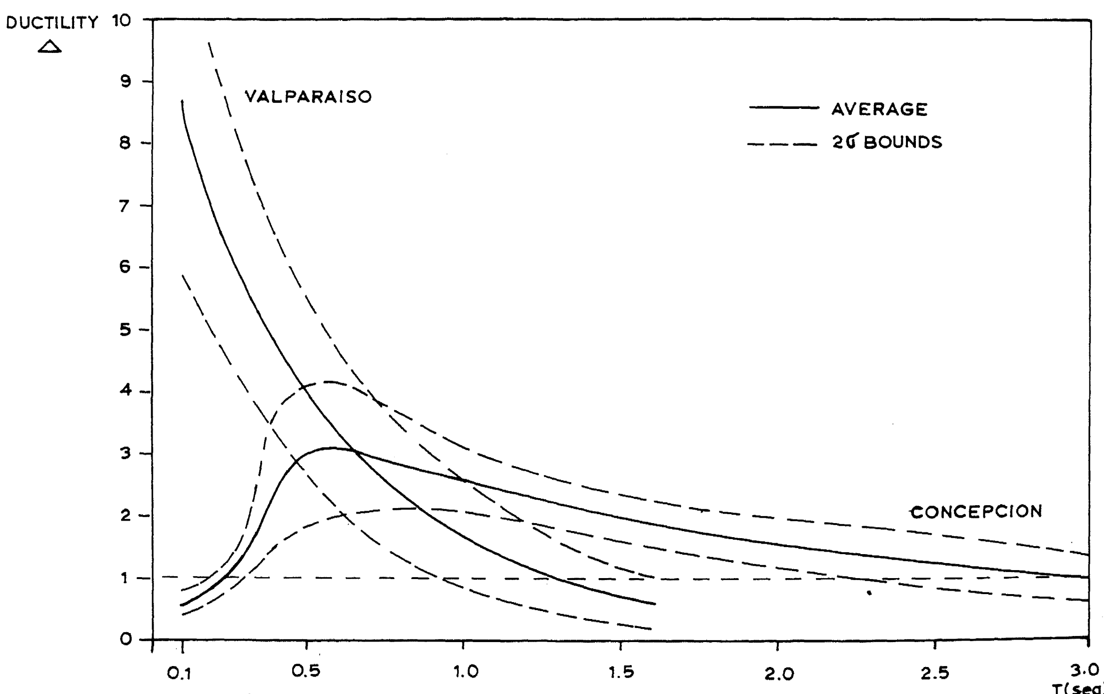

Fig. 2 DUCTILITY REQUIREMENTS. AVERAGE AND $\pm 2\sigma$ BOUNDS FOR 20 EARTHQUAKES IN SANTIAGO WITH EPICENTERS IN VALPARAISO AND CONCEPCION

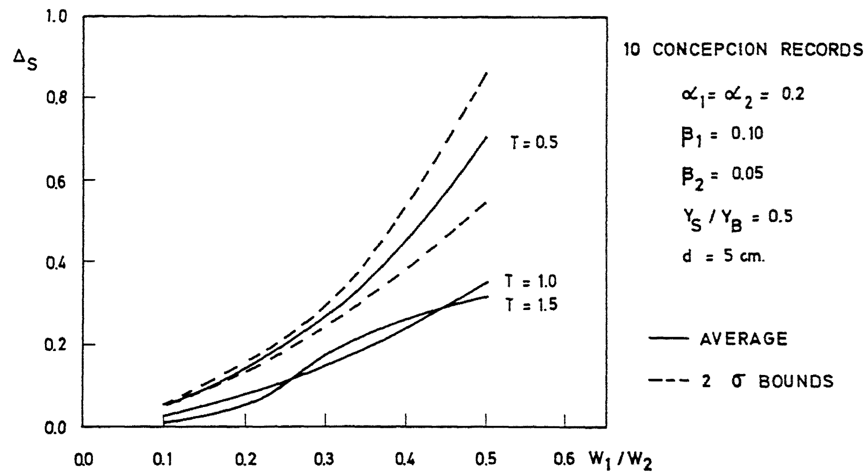

FIG. 3 STRUCTURE DUCTILITY REQUIREMENTS FOR 10 EARTHQUAKE RECORDS WITH EPICENTER AT CONCEPCION, CHILE.

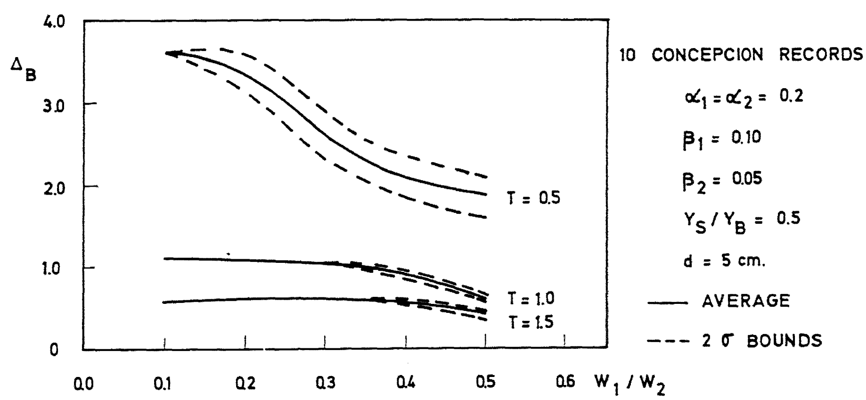

FIG 4 BASE DUCTILITY REQUIREMENTS FOR 10 EARTHQUAKE RECORDS WITH EPICENTER AT CONCEPCION, CHILE.

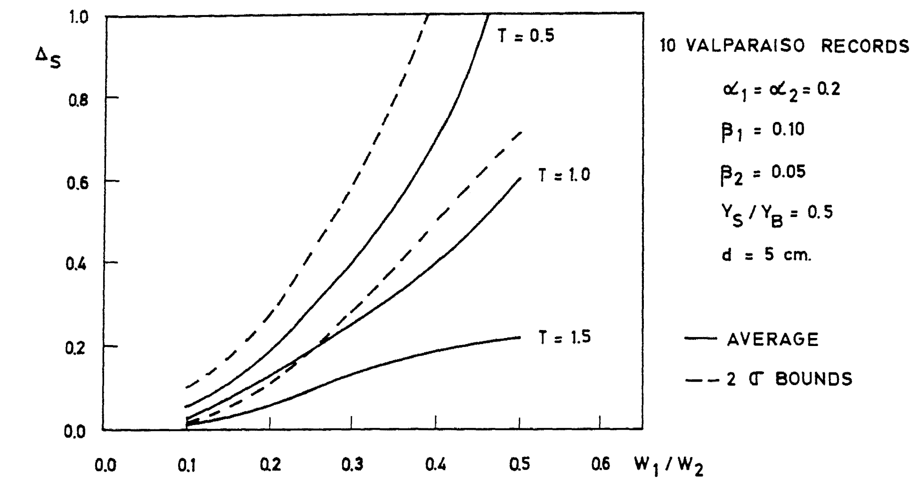

FIG. 5 STRUCTURE DUCTILITY REQUIREMENTS FOR 10 EARTHQUARE RECORDS WITH EPICENTER AT VALPARAISO, CHILE

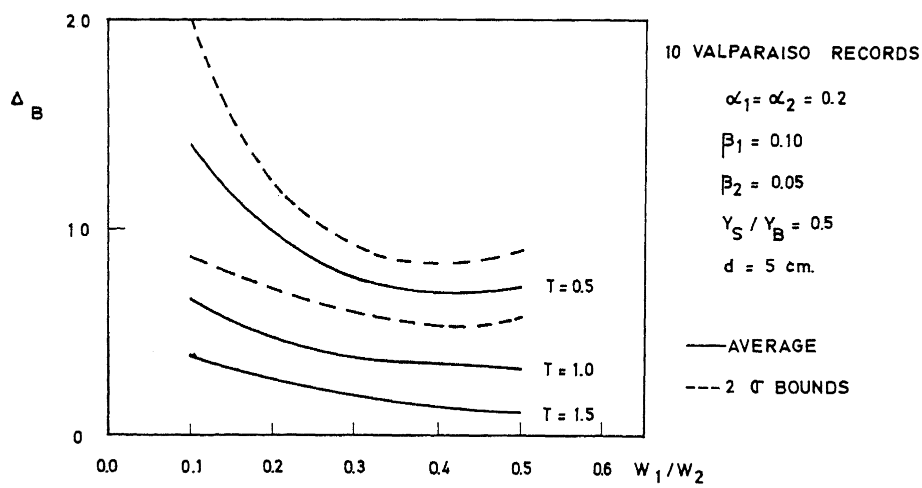

FIG. 6 BASE DUCTILITY REQUIREMENTS FOR 10 EARTHQUARE RECORDS WITH EPICENTER AT VALPARAISO, CHILE.