OPTIMIZATION CRITERIA FOR THE SELECTION OF GROUND MOTION ISOLATORS

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SUMMARY

A system for isolating building structures from ground motion excitation is developed and evaluated. The system proposed is a combination of suspension elements for the superstructure and energy-dissipating devices. The former are sets of vertical cables through which column footings transmit their loads to the foundation; energy-dissipating devices are characterized by bilinear hysteretic behavior, and are responsible for controlling building sway due to wind forces. A cost-benefit analysis is formulated for the structure-isolator-foundation system and applied for conditions prevailing in Mexico City. It is concluded that the system provides an economically efficient solution.

INTRODUCTION

A number of devices have been proposed aiming at isolating structures from earthquake ground motion. The system studied in this paper consists of a combination of suspension members and energy-dissipating elements. The former are sets of vertical cables through which column footings transmit their loads to the foundation; energy-dissipating devices control relative displacements between column footings and foundations and prevent building sway due to wind forces; they are characterized by hysteretic behavior, with their load-deflection curves selected in accordance with maximum probable wind forces and energy-dissipation requirements.

The dynamic response of a building supported on a system as described above is very sensitive to the length of the cables: the longer they are, the greater is the isolating effect; but the cost of the system and of the substructure required to house it grows with cable length. Practical applications of systems of the type proposed demand cost-benefit analyses, where the increased costs of using them are compared with savings in initial costs of structure and architectural elements and with present values of expected costs of damage.

An analysis is presented in this paper of the economic consequences on typical buildings of adopting different cable lengths, taking into account both initial costs and expected damage. Contrary to proposed practice, requirements for design of structure and architectural elements are not varied on account of the reduction in response expected from the influence of the isolators. The optimization analysis performed is thus restricted to considering the decreased costs of expected damage. Each structure studied was designed in accordance with the current Mexico City seismic design regulations. A set of isolating elements was assumed, and the dynamic response of the resulting system was studied for different intensities by means of a nonlinear step-by-step analysis.

SUSPENSION SYSTEMS

A constructive solution for a suspension unit is sketched in Fig. 1: a column footing is suspended on a set of vertical cables of length L hanging from a support frame, and a vertical cantilever acts as energy dissipator. The gap h between the column face and the inside edge of the support frame is determined so as to attain a sufficiently low probability of impact between column and frame, which for the

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I Institute of Engineering, National University of Mexico seismicity and ground motions characteristic of the soft-clay ground of Mexico City means taking *h* as 25 to 30 cm; the same gap is provided between footing edges and foundation members. Columns are interconnected above the support frame by means of the lowest floor-system.

Load-deflection characteristics of a number of energy-dissipating devices have been extensively studied by Skinner et al (1). Herein it is assumed that their behavior can be idealized as bilinear (Fig 3). The load-deflection curve of suspension unit is that of a simple pendulum having length L and a mass with weight equal to that of the column discharge W. Hence, if d is lateral displacement, the lateral shear taken by a suspension unit equals $f' = Wd/(L^2 - d^2)^{1/2}$, as shown in Fig. 2. The combined stiffness of suspension elements and energy dissipators is shown in Fig 4. Because W varies while the structure oscillates, the corresponding variation in lateral stiffness should be accounted for in response analyses. For systems subjected to one single horizontal ground motion component, the variations in stiffness produced by variations in column discharges can be disregarded when performing dynamic response studies, as they compensate throughout the foundation. However, variations in unit-stiffness produced by variations in column discharges associated with one horizontal ground motion component can give place to stiffness-eccentricities and hence to torsional oscillations when considering the response to a ground motion component orthogonal to the former.

An obvious limitation of a system as sketched in Fig. 1 is its inability to cope with upwards vertical accelerations greater than gravity; but these accelerations are extremely unlikely at Mexico City and at a large number of places and, furthermore it is not difficult to design a system capable of limiting vertical response while not imposing significant lateral restrictions. Indeed, the energy-dissipating devices can be detailed so as to provide the required vertical restriction.

Two important advantages of the suspension systems proposed are their simplicity and their tendency to return to their initial equilibrium position. The former entails high reliability of performance predictions; the former helps in controlling peak displacements and reduces problems associated with re-centering the construction after each earthquake.

EVALUATION CRITERION

Cost-benefit studies where based on comparing initial construction costs associated to different cable lengths with present values of expected damage. For a given system, the present value of expected damage can be expressed as $\nu_o E_1(D)/\gamma$ where ν_o is the rate of occurrence of earthquakes having intensity above a sufficiently low threshold value, γ is an actualization coefficient (similar to interest rate) for utilities, and $E_1(D)$ is the expected cost of damage given the occurrence of an earthquake with intensity above the specified threshold value. The latter variable is obtained as $E_1(D) = \int f_I(y)\, E(D/y)dy$, where $f_I(y)$ is the probability density function of intensities given occurrence of an earthquake and $E(D/y)$ is the conditional expectation of damage for an earthquake with intensity y; this expectation can be estimated by means of nonlinear response analysis for diferent intensities and empirical damage-response expressions.

SEISMIC RESPONSE STUDIES

A number of three-bay, 15 and 25 stories high rigid frame buildings were studied. Their properties were determined in accordance with the requirements of Mexico City Building Code. They were subjected to accelerograms obtained by scaling in intensity several local records on soft soil (2). Scaling factors corresponding to different return periods were determined in accordance with Ref 3, and damage-deformation relations were obtained from Ref. 4.

The buildings selected were assumed to respond as shear beams with bilinear load deflection curves. They were analyzed as two-dimensional systems by means of a step-by-step integration procedure using Wilson's θ method. The influence of torsional oscillations due to interaction between stiffness of the suspension units in one direction and column discharges due to lateral oscillations in an orthogonal direction were thus not directly covered in the response analysis, but it had been previously verified that they would not significantly influence either response or damage.

RESULTS AND CONCLUSIONS

Peak relative displacements between column bases and foundation did not exceed 16 cm for earthquakes with return periods as long as 80 years. Typical curves relating total costs (initial plus damage) are shown in Figs. 5 and 6. Construction costs include those of structural and architectural elements as well as those of suspension units, energy-dissipating devices, and auxiliary foundation elements. Optimum cable lengths are 2.5m respectively for 15- and 25-story buildings. For $\gamma = 0.05$ (which is too low according to present inflation rates), savings in present value of expected damage can amount to 25 and 14 percent of construction costs exclusive of isolation systems. The cost of the latter is of the order of 3 percent of total construction cost. Hence, the system provides an economically efficient solution for the conditions considered.

The results presented are valid for the seismic and eolic conditions prevailing in Meixco City, i. e. far epicenters, soft soil and moderate winds. For locations characterized by firm ground, optimum cable lengths should be shorter than those determined herein.

REFERENCES

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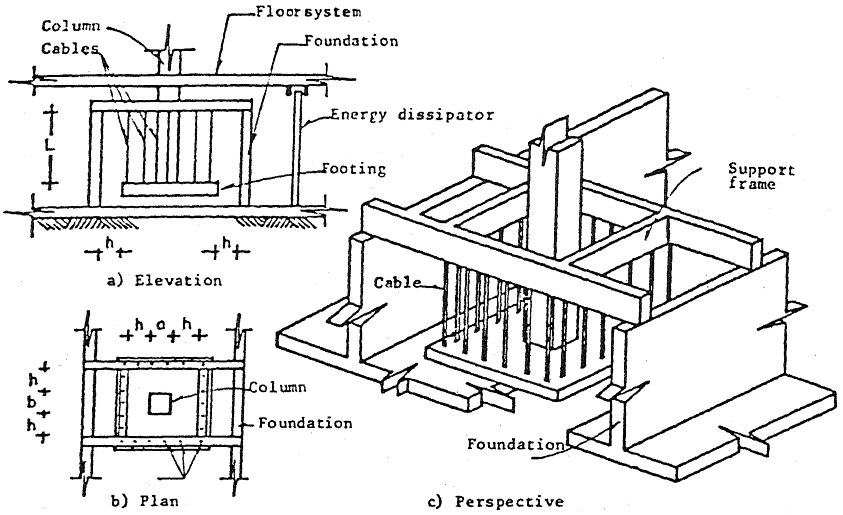

FIG 1 SUSPENSION UNIT

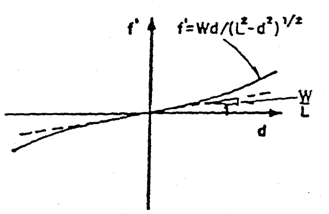

FIG 2 FORCE-DEFLECTION BEHAVIOR OF PENDULUM WITH LENGTH L AND WEIGHT W

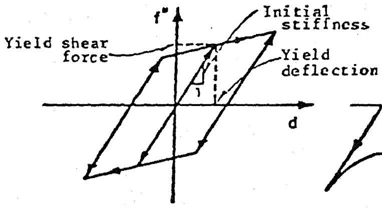

FIG 3 FORCE-DEFORMATION BEHAVIOR OF BILINEAR HYSTERETIC ELEMENTS

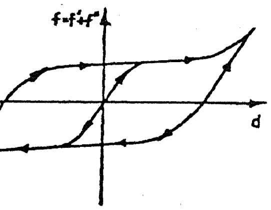

FIG 4 FORCE-DEFORMATION BEHAVIOR OF ISOLATOR-DISSIPATOR SYSTEM

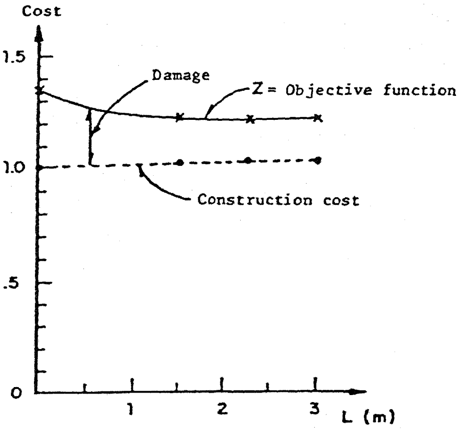

FIG 5 OBJECTIVE FUNCTION FOR 15-STORY BUILDING

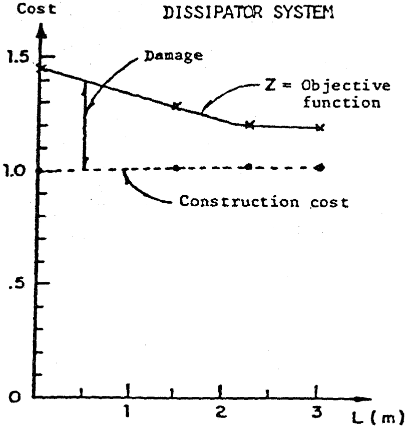

FIG 6 OBJETIVE FUNCTION FOR 25-STORY BUILDING