DUCTILITY REQUIRED IN CODE DESIGNED STRUCTURES

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SYNOPSIS

The dynamic response of elastoplastic systems subjected to a set of earthquake records is analyzed using Montecarlo techniques to evaluate the general trends of nonlinear response spectra associated to various ductility requirements. These response spectra, for various earthquake intensities, are compared to a typical design spectrum as specified by earthquake resistant design regulations, to determine typical ductility requirements in code designed structures.

INTRODUCTION

The main factors involved in the seismic behavior of structures for earthquake resistant design are: a) the high degree of uncertainty, both in the ocurrence and form of seismic motions (1)[#], and b) the instantaneous incursions of structures into the inelastic range during peak value of response.

One of the first attempts to consider the effect of uncertainty in the evaluation of the response was suggested by Housner (2) who constructed smooth average seismic response spectra in order to eliminate the particular details of specific accelerograms and to preserve the main trends, typical to most earthquake records.

The need to accept instantaneous inelastic behavior is based on a practical criteria that recognize the impossibility of providing full seismic protection to structures, specially during very short time intervals, insignificant compared with the life of the structure. However, during these instantaneous incursions into the inelastic range, the structure must have the adequate ductility to avoid collapse.

These concepts are part of earthquake resistant design philosophy, whose main criteria is based in the specification of strength, rather than loadings, through a design spectrum. This design spectrum can be

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[#] Numbers in parentheses refer to bibliography at the end of the text.

made equivalent to a response spectra of an elastoplastic system, reduced by an overload coefficient or safety factor. Based in this equivalence, it is possible to estimate the ductility requirements implied by a given strength level, specified by codes, as a function of seismic intensity.

ANALYSIS PROCEDURE

The results presented in this paper are based on a research program (3) oriented to determine the response of elastoplastic systems subjected to a set of earthquake excitations.

The damped elastoplastic system shown in Fig. 1 has been selected for its simplicity to describe stiffness, strength, ductility and internal damping of structural elements. These parameters have been selected within a wide range covering almost all practical cases: a) The stiffness, defined in terms of the natural period, in the range 0.1 to 3.0 sec., b) The strength, as a fraction of weight, in the range 5% to 30%, c) Ductility factors up to 6, and d) Damping ratios in the range 2% to 10%.

The excitation has been represented by eight accelerograms corresponding to two real earthquakes: a) N-S component of El Centro 1940 earthquake, and b) S69E component of Taft 1952 earthquake, and six artificial earthquakes, Nos. 1, 3, 10, 13, 14 and 20 of a set of 20 earthquake records generated (4) to simulate earthquakes recorded on firm soil at moderate epicentral distances.

The effect of earthquake intensity is considered by simple amplification factors applied to the accelerograms, in order to define three levels of intensity, I1, I2 and I3, as indicated in Table I.

ANALYSIS OF RESULTS

The results obtained from this procedure are evaluated in terms of the maximum displacement of an elastoplastic system of specified yield level, and the time history of energy dissipation.

The maximum instantaneous response is shown in Figs. 2 - 4 in the form of a response spectra for the various intensity levels I1, I2 and I3, for damping ratios of 2% and 5% and for ductility requirements of 1,4 and 6. As a comparison, the design spectrum specified by the Chilean Code for Earthquake Resistant Design of Buildings has been included in these graphs, amplified by an overload factor of 2.0 to transform it from a allowable level to a yield level.

CONCLUSIONS

The following general conclusions can be drawn from a detailed analysis of these results:

a) Damping, very useful in reducing structural response, is more efficient for short period structures. Its usefulness decays notably in structures with large ductility requirements or that perform numerous incursions into the inelastic range.

b) In long period structures, in the range of 1.5 to 3 sec., the ductility requirements are low and almost independent of strength.

c) In rigid structures, ductility required is very dependent of strength.

d) The response of elastoplastic systems is not as sensitive to variations of the period as in elastic systems.

e) The total energy dissipated by an elastoplastic system is practically independent of the strength level and of the damping ratio.

f) Comparing the ductility requirements of an elastoplastic system with the specifications of the Chilean Code, the ductility requirements implied in this code can be estimated.

Table II shows the ductility requirements implied in the Chilean Code for various seismic intensities. From this table it can be appreciated that these requirements are not uniform in the range of typical periods of vibration.

REFERENCES

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Table I Seismic Intensity

Intensity Level	Housner Intensity (ft)	Mercalli Intensity	Maximum Acceleration (%g)
I1	1,5	VI - VII	17
I2	2,0	VII	22
I3	2,5	VIII	27

Table II - Ductility requirements

	$\xi = 2\%$		$\xi = 5\%$		$\xi = 10\%$
I1 :	$T < 0,5$:	2,5			
	$0,5 < T < 1,8$:	2,0		2,0	0,5
	$T > 1,8$:	2,5			
I2 :	$T < 0,5$:	4,0	$T < 1,0$:	3,0	2,0
	$T > 0,5$:	3,0	$T > 1,0$:	2,5	
I3 :	$T < 0,4$:	6,0	$T < 0,5$:	4,0	
	$0,4 < T < 1,0$:	4,0	$0,5 < T < 2,0$:	3,0	3,0
	$1,0 < T < 1,5$:	3,5	$T > 2,0$:	4,0	
	$T > 1,5$:	4,0			

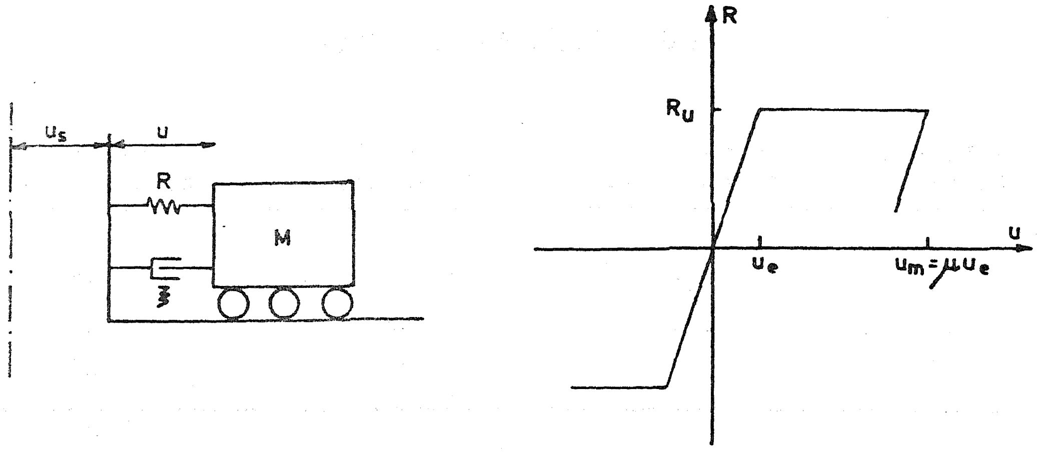

FIG. 1 ELASTOPLASTIC SYSTEM

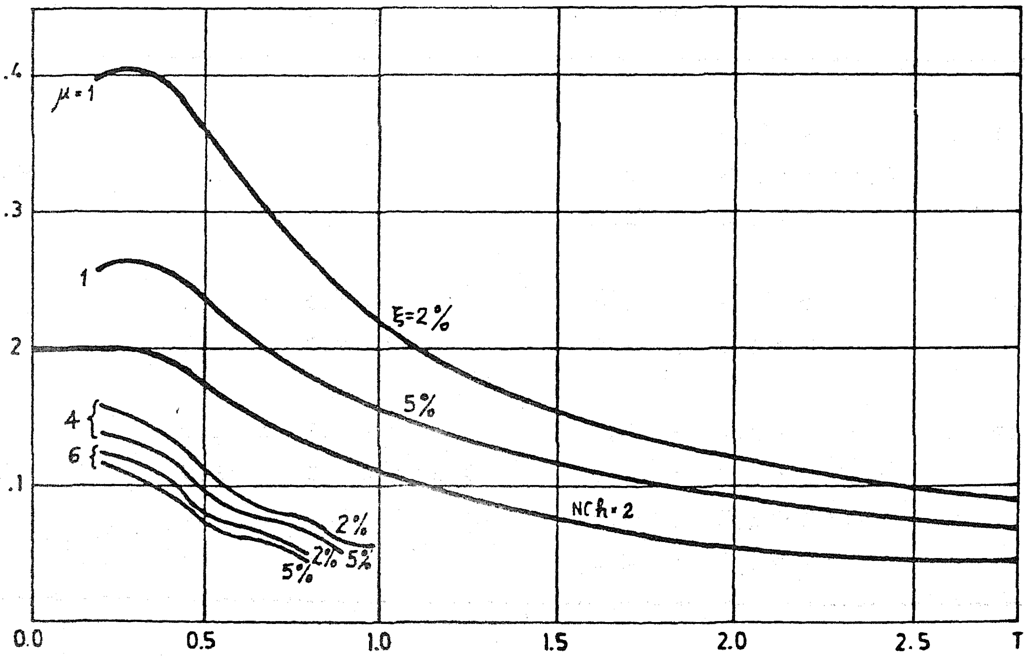

FIG. 2 ELASTOPLASTIC RESPONSE SPECTRUM - INTENSITY II

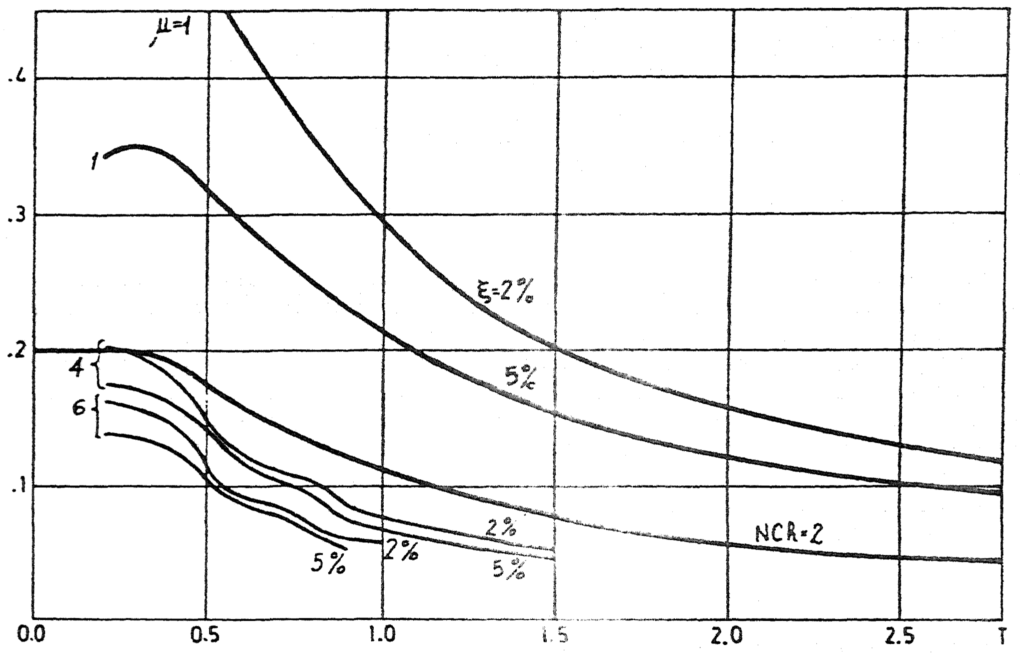

FIG. 3 ELASTOPLASTIC RESPONSE SPECTRUM - INTENSITY I2

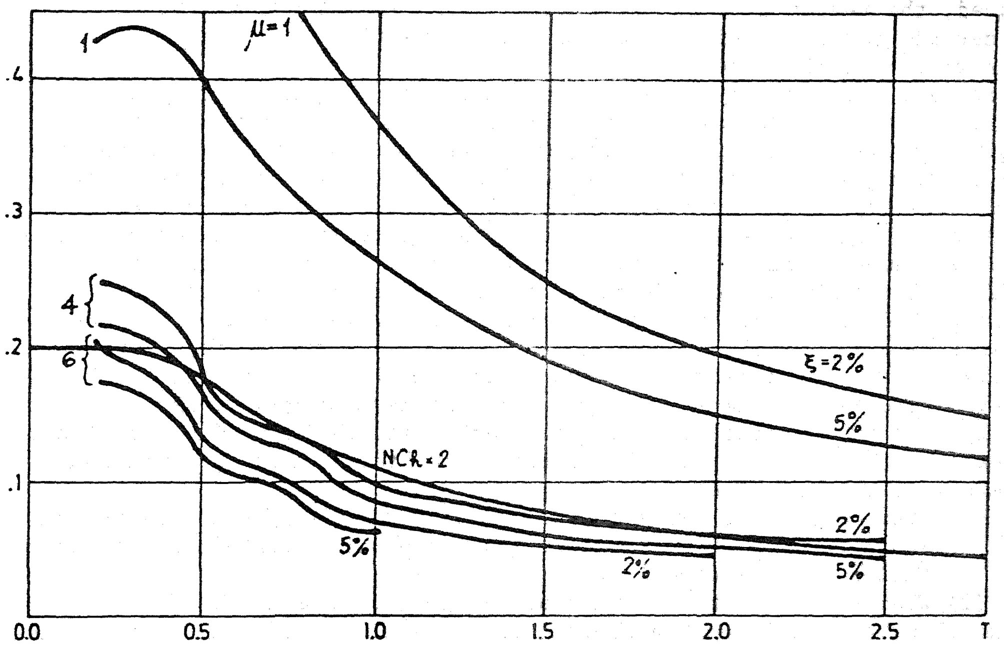

FIG. 4 ELASTOPLASTIC RESPONSE SPECTRUM - INTENSITY I3