DUCTILITY REQUIREMENTS FOR SOME NONLINEAR SYSTEMS SUBJECTED TO EARTHQUAKES

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SYNOPSIS

Following the lines of previous work, notably that of Veletsos and Newmark (2), a collection of nonlinear one-degree-of-freedom systems with different force deformation relationships were analyzed under five earthquake records, characteristic of motions on firm ground, scaled to various intensity levels. Some results of these analyses are presented, showing the yield force necessary to limit required ductility to any desired level, as a function of the elastic natural period and the intensity of motion. These forces are compared to the values that would be obtained from application of the Uniform Building Code for zone 3, and the implications of this comparison are discussed.

1. INTRODUCTION

The work described in this paper was conducted as part of an ongoing research project on optimum seismic design criteria for buildings. From published experimental results a set of nonlinear springs with different force deformation relationships were selected as representing the interstory behavior of various structural components (1), and it was desired to assess the sensitivity of the results (ductility requirements in particular) to the models and variations in their basic parameters. Systems studied included elasto-plastic and bilinear springs representing the behavior of unbraced steel frames, stiffness degrading models representing braced steel frames or reinforced concrete frames and strength and stiffness degrading springs for infilled frames. Fractions of critical damping β in the elastic range of 0, 5, 10 and 20% were considered for each system (independently and in addition to the loss of energy by hysteresis in the inelastic range).

2. GENERAL CONSIDERATIONS

For each type of spring, systems with initial natural periods of 0.1, 0.25, 0.5, 1, 2 and 4 seconds were studied. Each one of these systems (with a given natural period and fraction of critical damping) was then subjected to base motions corresponding to the accelerograms of the NS and EW components of the 1940 El Centro earthquake, the NW and SE components of Taft (1952) and the SW component of Olympia (1949). In order to compare and average results these records were scaled so as to have for any run the same peak acceleration, the same value of Housner's intensity or the same value of Arias' intensity. It was found that this third procedure yielded the smallest variation from one motion to another, although results obtained by the second procedure were very similar. An average and an envelope curve were then obtained for each system relating ductility factor μ (defined as the ratio of the maximum strain to the yield strain)

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d) It would seem that for single-degree-of-freedom systems, a variation of the C coefficient as suggested by the Uniform Building Code will not provide the same ductility requirements for different periods. While flexible systems designed this way are likely to remain elastic, stiff systems and particularly those with periods between 0.1 and 0.5 seconds may require very large ductilities. A variation of C inversely proportional to the period for $T > T_o$ (T_o function of μ and β) would agree better with the constant ductility curves obtained in this study (1).

e) Extrapolation of the previous conclusion to actual structures (multi-degree-of-freedom systems) must be done with care, since higher modes are likely to be important for flexible buildings, whereas stiff buildings may entail a larger value of the K factor. Even so, analysis of different buildings seems to confirm the same overall trend. Flexible structures designed by the Uniform Building Code for zone 3 remain often elastic under an earthquake motion of the intensity of the 1940 El Centro, whereas stiff buildings require often substantial yielding.

REFERENCES

1. Anagnostopoulos, S.A., "Non-linear Dynamic Response and Ductility Requirements of Building Structures Subjected to Earthquakes," Report R-72-54, M.I.T. Department of Civil Engineering.
2. Veletsos, A.S., and Newmark, N.M. ,"Effect of Inelastic Behavior on the Response of Simple Systems to Earthquake Motions," 2nd World Conference on Earthquake Engineering, Vol. II.
3. Clough, R.W., and Johnston, S.B., "Effect of Shiffness Degradation on Earthquake Ductility Requirements," Japan Earthquake Engineering Symposium, 1967.
4. Kaldjian, M.J., and Fam, Wm. R.S., "Response of Steel Frames to Earthquake Forces," Steel Research for Construction Bulletin No. 11, Nov. 1968.
5. Veletsos, A.S., "Maximum Deformations of Certain Non-linear Systems," 4th World Conference on Earthquake Engineering, Vol. II.
6. Husid, R., "Gravity Effects on the Earthquake Response of Yielding Structures," California Institute of Technology, Research Report 1967.