NON-LINEAR DYNAMIC ANALYSIS OF BUILDINGS WITH TORSIONAL EFFECTS

by

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SYNOPSIS

The nonlinear dynamic response of complete buildings can be investigated using a simplified mathematical model. The masses, lumped at the floor levels, are connected with shear and bending springs whose characteristics are estimated from the properties of various structural and nonstructural components. The shear springs, forming close-coupled systems, approximate the behavior of frames for which axial shortening of the columns is not important, while the bending springs, leading to far-coupled systems, are used for shear walls and boxes. Three degrees of freedom are considered per floor. Results include time histories as well as maximum and average effects.

1. INTRODUCTION

While a large number of computer programs have been developed in the last few years for the dynamic analysis of complete buildings in the linear elastic range (including braced and unbraced frames, shear walls, boxes, shear panels etc.) most of the research done on the inelastic dynamic response of buildings has been limited to the study of simple multistory plane frames (2), (3), (4), (5), or to combinations of frames and shear walls interacting without torsion (2).

Even with models where the spreading of yielding and inelastic axial effects are neglected, analysis of a complete building by these methods becomes economically prohibitive for design purposes. Furthermore, most of these studies ignore the possibility of brittle or shear failures, being primarily intended for ductile frames. In this paper a simplified model, which incorporates space behavior and includes such factors as stiffness and/or strength degradation, nonstructural elements and possibility of brittle failures, is outlined, and results from the analysis of several buildings are discussed.

2. GENERAL CONSIDERATIONS

The mathematical model and the corresponding computer program were developed as part of an ongoing research project on optimum seismic design criteria for buildings (1). The main objective was to be able to reproduce the overall behavior of a building in the linear and nonlinear ranges at low computational costs, and to use this information for a gross estimate of damage in several types of buildings as a function of the design strategy and the intensity of the earthquake motion. The analysis

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procedure was thus intended, not to give detailed information on any particular member or joint, but rather to provide average overall ductility requirements for the various components in each story.

From published experimental results a set of eight different nonlinear springs was implemented to reproduce the interstory behavior of various structural and nonstructural components such as masonry partitions or isolated block walls, unbraced, braced or infilled steel frames, open, infilled or partially infilled concrete frames, and shear walls or elevator boxes. Partitions, isolated block walls, and frames, are then assumed to act as close-coupled systems, whereas a far-coupled system is used for shear walls or boxes. The program will automatically generate, if so desired, the set of springs corresponding to a given component, determining the characteristics of each spring from the properties of columns, girders, bracing and panels. The user has, however, the option to select himself and to specify directly any set of springs. In addition, the shear capacity of each component is determined and compared at each step to the actual shear force to detect the possibility of brittle failures.

The model assumes that each floor has a slab which can act as a rigid diaphragm, leading thus to a system with three degrees of freedom per floor, (two displacements and a torsional rotation). The program computes the shear forces that have to be transmitted by the diaphragm and could therefore detect possible cracking or failure of the slab, but this option is not implemented at present.

One of the main limitations of the model is in the fact that axial deformation of the columns is neglected in order to obtain the simplified shear type behavior for the frames. This restricts its applicability to buildings with moderate slenderness ratios, but a large number of practical structures fall within this range.

The resulting differential equations of motion are written in matrix form as

$$M\ddot{U} + C\dot{U} + F(U) = E$$

where M is a diagonal mass-inertia matrix, C a damping matrix that will yield any desired modal dampings in the elastic range, F a vector of spring forces (nonlinear function of displacements), and E the vector of excitation forces for the two principal directions. These equations are solved numerically by using a simple step-by-step integration procedure known as the "constant velocity" method (6). Extensive testing showed this method to give results comparable in accuracy, and often better, than those obtained using more complex procedures (1).

Finally, the effect of gravity loads on the deformed geometry of the building (P-Δ effect) is also included, if desired by the user.

3. RESULTS AND CONCLUSIONS

Results of the program include selectively for each floor or element time histories as well as average and maximum values of accelerations, displacements, forces and deformations, plus maximum ductility factors and permanent set for the different springs, and special flags indicating failure of any component. It is intended in the future to relate these quantities to some measure of damage in order to obtain an indication of possible economic loss as a function of earthquake intensity for a particular design.

The program was tested in the elastic range by comparing results to those obtained from a general and more accurate program for linear dynamic analysis of complete buildings developed some years ago at M.I.T. Agreement was in all cases extremely satisfactory.

Several buildings were analyzed in the inelastic range for motions of varying intensity. For similar structures, values and distribution of ductilities (1) were comparable to those reported by Clough (2). Results for a 13-story steel-frame building, an 11-story concrete-frame structure and a 17-story concrete-frame and shear-wall building are shown in figs. 1 to 3. Analysis of a five-story building with a rather large eccentricity confirmed the fact reported by other researchers that dynamic torsional effects cannot be accounted for by imposing a set of static forces with the same eccentricity. In fact for the building considered it was the frame farthest from the center of mass which had largest dynamic forces in the elastic range, contrary to what a static analysis would predict. The distribution of forces among the frames changes considerably along the height of the building as some of the elements start to yield, as shown in fig. 4.

While more work is necessary to refine and validate the selection of the spring type and characteristics for various structural components, it would seem at present that the proposed model provides an economic and reasonably accurate procedure to estimate overall behavior and ductility requirements for a wide class of practical buildings. The model is not applicable to structures where axial effects are important, but LaTona's work (5) seems to indicate that more complicated models may be equally suspect in this case. The computer program is now being used for a more complete set of parametric studies of buildings designed by different criteria.

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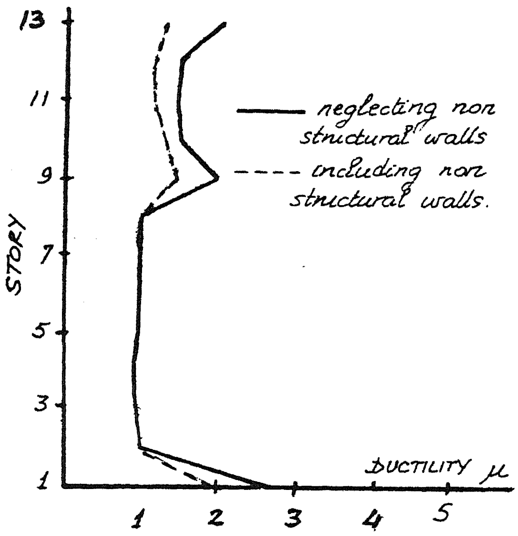

FIG 1. 13 STORY STEEL FRAME

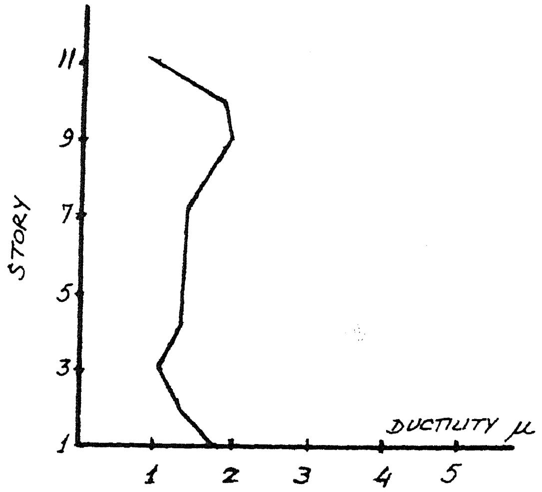

FIG 2- 11 STORY CONCRETE FRAME

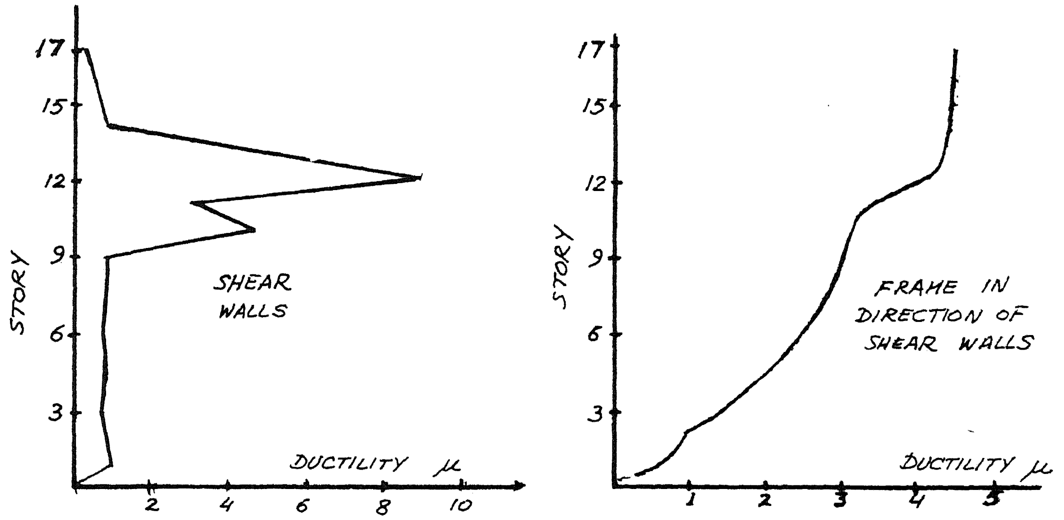

FIG 3. 17 STORY SHEAR WALLS AND CONC. FRAME BUILDING

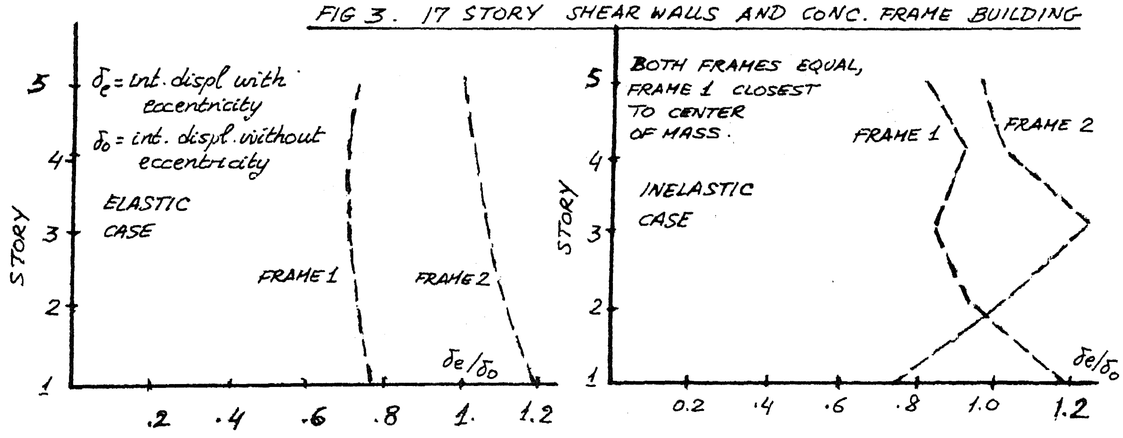

FIG 4. EFFECT OF TORSION ON INTERSTORY DISPLACEMENTS FOR 5 STORY BUILDING