USE OF DYNAMIC ANALYSIS IN SEISMIC DESIGN

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SUMMARY

A study is made of the feasibility and usefulness of a seismic design method for multistorey steel frame buildings. The method employs a time-series elastic response analysis of the structure for a ground motion compatible with a design response spectrum. The correlation between the elastic and elasto-plastic response is investigated and it is suggested that the design forces in the members of an elasto-plastic structure can be obtained by applying appropriate reduction factors to the forces obtained in an elastic analysis.

INTRODUCTION

A dynamic analysis is essential for the seismic design of irregular building structures. The usual practice is to carry out an elastic analysis of the structure for an appropriate ground motion and then to design the structure for a fraction of the forces so obtained. This fraction is usually taken as equal to a ductility factor appropriate for the structure. The ductility factor is a measure of the capacity of structure for absorption of energy through inelastic deformation and is defined as the ratio of the total elasto-plastic deformation to the yield deformation. The relationship between ductility and force reduction factors is however dependent on the ground motion, period of vibration of the frame and the magnitude of gravity loads. Some of these factors are studied in this paper.

While inelastic deformations are accepted in a building subjected to a severe seismic excitation, it is considered desirable that the inelasticity be confined to girders and that the columns remain elastic. It is shown in this study that for the above objective to be fulfilled, the reduction factor to be applied to the column forces should be smaller than that applied to the beam moments.

In the dynamic analysis reported here, inelastic material behaviour was modelled by using an elasto-plastic hysteresis relationship applicable to steel members. The ground motion used was such that its spectrum matched an average design response spectrum.

EFFECT OF INELASTICITY ON RESPONSE

Single Degree of Freedom System

A single storey frame similar to the first storey of the frame in Fig.2 was analyzed for 15s. of the selected ground motion. The mass of the frame was adjusted to give 18 different values of the period, giving in effect 18 different frames. For each frame an elastic analysis was carried out first.

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This was followed by an elasto-plastic analysis in which the strength of each member was set at a value equal to one fourth the maximum moment obtained in it during the elastic analysis.

Figure 1a presents a comparison of the maximum elasto-plastic displacement and the maximum elastic displacement for each period of vibration. Figure 1b shows the displacement ductility of the frame and the rotation ductility of the girder. The displacement ductility μ_Δ, is defined as the ratio of total elasto-plastic displacement to the displacement at yield. The rotation ductility, μ_Θ, is defined as the maximum elasto-plastic rotation at an end hinge to the yield rotation at the same location. The results show that the displacement ductility is higher than the factor 4 used in obtaining the design moments. The rotation ductility is still higher, at times reaching a value that may be difficult to provide for in design.

To investigate the effect of gravity load on response, elasto-plastic analyses were repeated for all the eighteen frames with a uniformly distributed load added to the girder. The strength of each member was set as equal to the sum of one fourth the moment obtained in elastic analysis and the gravity load moment. The rotation and displacement ductility factors for frames carrying gravity loads are shown in Fig.1b. The ductility demand is now considerably reduced and is closer to the force reduction factor of 4.

Multi-Degree of Freedom System

The three storey frame shown in Fig.2 was studied. The mass at each floor of the frame was assumed to be the same and equal to a reference mass m. The reference mass was varied to give six different values of the fundamental period, ranging from 0.3s to 0.8s, thus in effect giving six different frames. An elastic analysis was carried out for each frame for the selected ground motion. In the elasto-plastic analysis of each three storey frame, the girder strengths were set at one fourth the maximum moment obtained from the elastic analysis. To avoid plastic hinges in the columns, column strengths were kept higher than the maximum elastic moments, except in the first storey, where the strength of each column was set equal to half the maximum moment obtained for that column during the elastic analysis.

The ductility ratios for girders obtained from the elasto-plastic analyses are shown in Fig.3a. It will be observed that, even though a uniform force reduction factor of 4 was used in obtaining the girder strengths, the girder ductility is not uniform, and is, in fact, much larger than 4 in some cases.

The three storey frames were next analysed for the combined effect of gravity loads and seismic vibrations. The strength of each girder was increased so that it was equal to the sum of the design earthquake load moment and the gravity load moment. The girder ductility ratios obtained from the analysis are shown in Fig.3b. The ductility demand in all the girders is now observed to be closer to the reduction factor of 4.

The reduction factors obtained for the column moments and colum axial loads are shown in Figs.4 and 5 respectively, a reduction factor being defined as the ratio of the maximum elastic response value to the corresponding elasto-plastic response value. The top moment in an uppermost column is constrained to be equal to the top storey girder end-moment to satisfy equilibrium; the reduction factor for such a moment should be equal to 4. The middle storey columns are designed to remain elastic, and it is of interest to note that the reduction factor for these columns is equal to about 2, that is only about half of the reduction factor for girders. When no gravity loads are present, the reduction factor for column axial loads is the same as that for the girders. In the presence of gravity loads, it decreases to about half that for the girders.

APPLICATION TO DESIGN

From the analyses presented in this paper, it is evident that the correlation between the results of an elastic and an elasto-plastic seismic analysis is only approximate. However, one can be reasonably certain that if the seismic design forces in the members of a frame are obtained by applying appropriate reduction factors to the forces obtained through an elastic analysis, the ductility demand in girders will be of the same order as the girder reduction factor. It is also evident from the results for the three storey frame and similar results obtained by the author for several other tall frames, but not reported here, that if the inelasticity is to be confined to the girders, the reduction factors to be applied to the column forces should be smaller than the one applied to the girder moments. The magnitude of reduction factors will depend upon the ductility capacity of the members. For steel structures, it seems appropriate to use a reduction factor of 4 for the girder end-moments and a reduction factor of 2 for the column moments and column axial-loads.

Acknowledgement

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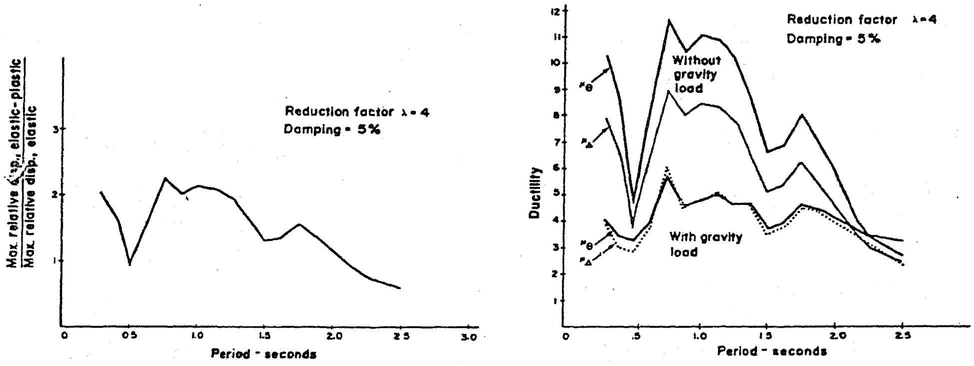


1(a) 1(b)

FIG. 1 RESPONSE OF SINGLE STOREY FRAME

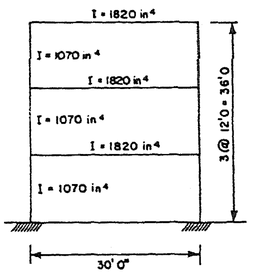
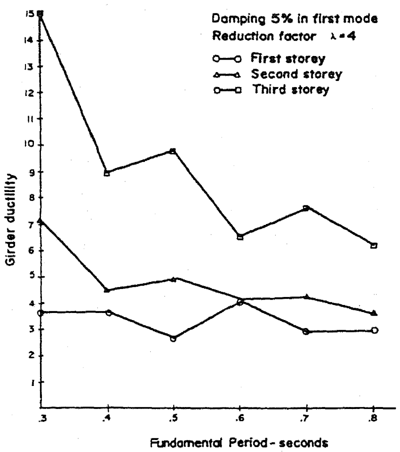
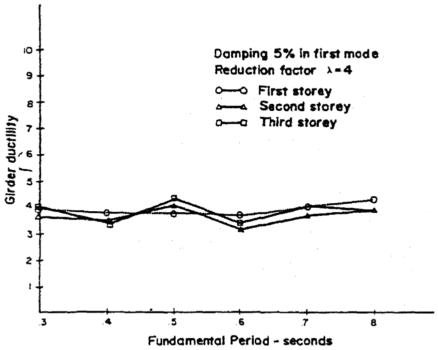


FIG. 2 THREE STOREY FRAME

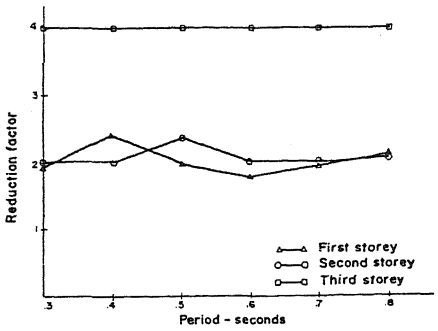


3(a) Response Without Gravity Load

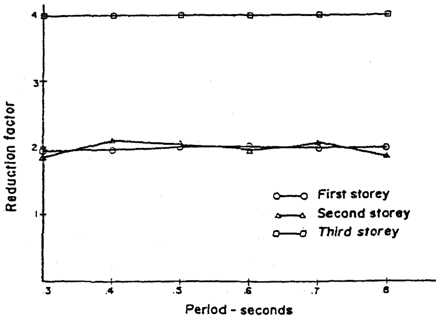


(b) Response With Gravity Load

FIG. 3 RESPONSE OF THREE STOREY FRAME



(a) Response without Gravity Load



(b) Response with Gravity Load

FIG. 4 REDUCTION FACTORS FOR COLUMN MOMENTS IN THREE STOREY FRAME

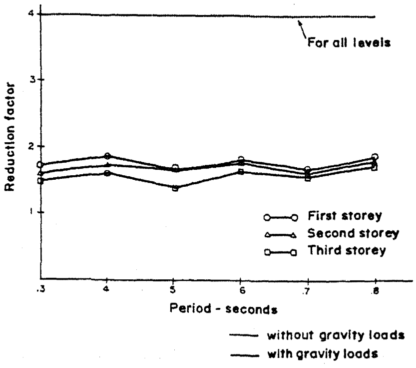


FIG. 5 REDUCTION FACTORS FOR COLUMN AXIAL LOADS IN THREE STOREY FRAME