Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VII)

12-2-4

PERFORMANCE OF WEAK FIRST STORY BUILDINGS SUBJECTED TO THE MICHOACAN-GUERRERO, 1985 EARTHQUAKE

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SUMMARY

A study is presented of the influence of the type of infill walls (brittle or ductile) on the dynamic response of weak-first-story buildings, subjected to a narrow band earthquake (SCT-EW, Mexico, September, 1985), as well as of the relation beteween the amplitude of that response and its dominant period. The buildings studied had an initial fundamental period moderately smaller than the dominant period of the excitation. Ductility demands at the first story of buildings with different ratios of stiffnesses of the first two stories are computed. On the basis of the results obtained, the influence of the mentioned variables on the response is discussed.

INTRODUCTION

During the 1985 Michoacán-Guerrero, Mexico, earthquake several buildings with weak first story located in the soft soil area in Mexico City were damaged. In some of those cases the damage did not affect structural members (e.g. shear failure of infill walls), but at least five of the mentioned buildings were identified as having suffered collapse by instability of their first story (which totally disappeared), and others showed severe structural damage in the bottom column, as a consequence of rocking, torsion and p-Δ effects. However, many others survived the shock unscathed.

The question arises of understanding the differences in damage levels between apparently similar structures located near each other. This study, which is a step in the process of answering that question, shows that the response of the structure is strongly influenced by the ratio of the dominant period of the response to that of the excitation (in particular when dealing with narrow band ground motion).

OBJECTIVES

It is intended to understand the dynamic behavior of buildings with weak first story, for those cases when the initial fundamental period, T, is much shorter than the dominant period of a narrow band ground motion excitation, such as the EW component of the record obtained in the parking lot adjacent to the SCT building in September 1985. The dominant period of the latter equals 2s, and the duration, t_o, of the most intense portion of the record (90 percent of the energy liberated) is 47s. For the purpose mentioned, a parametric study is carried out, concerning the dynamic response of this type of buildings with two different types of walls (brittle,B, and ductile,D), and ductility demands at the first story are estimated.

STRUCTURES STUDIED

Two reinforced concrete buildings frames, respectively 5 and 12 stories high, were designed for a lateral force coefficient C_s equal to 0.06, using a static method of seismic response analysis, and checking that the peak displacement at the top of a given building did not exceed 0.016 of its height. Wall panels were added to the frames, at all stories but the first one. The fundamental periods of the buildings were 0.67 and 1.4s respectively, and the ratios of the lateral stiffness of the second story to that of the lowest one were equal to 4 and 0.9.

Both brittle (B) and ductile (D) walls were included in the study. In the second case (D), the constitutive lateral-force curves are of hysteretic type, with stiffness degrading (Fig. 1a), while in the first case (B) stiffness degradation is ignored, and it is assumed that the strength of a wall becomes zero when the latter reaches a lateral deformation equal to twice its yield deformation (Fig. 1b). In both cases, hardening plastic behavior is considered, where the second branch of the force-deformation curve has a slope equal to 2 percent of the corresponding initial stiffness. Viscous damping equal to 5 percent of critical is assumed.

STRUCTURAL MODELS

The buildings were analyzed by means of program DRAIN-2D (Ref. 1). Simple "bending and panel" elements were used in case B, while case D made use of "bending" and "truss" elements. The latter case was idealized as shown in Fig. 2. Floor masses were concentrated at the nodes at the ends of beams and columns.

PARAMETRIC STUDY

Two sets of structures were analyzed, each corresponding to a given stiffness ratio k_2/k_1 (4 and 0.9), with different strength ratios R_2/R_1 (second to first story). For each case, time histories of displacements and internal forces were obtained, and from those histories the peak ductility demands at the first story were derived. Fig. 3 shows the histories of lateral deformation of the first story for the ratio R_2/R_1 equal to 1.2, corresponding to five-story structures, both with brittle and with ductile walls (5B, 5D). It is observed that the dominant response periods are nearly equal, but the response is lower in case 5D, as should be expected, given that a large portion of the energy dissipation is due to the hysteretic behavior of the walls. The first story ductility demand, μ_1, for R_2/R_1 equal to 1.2, is slightly greater than the double for buildings with brittle walls as compared to the case of ductile walls. Fig. 4 shows first-story ductility demands for other values of R_2/R_1. A high value of this ratio indicates that the walls added to the frames are sufficiently strong as to permit the upper portion of the building to respond elastically, while the first story develops hysteretic behavior. In this case, the first story ductility demand depends strongly on the ratio of the dominant period of the response to that of the excitation. If the modified "period" of the non linear response is much shorter than the latter, the response is small; however, if both periods are sufficiently close, a phenomenon similar to resonance takes place (although the term "resonance" is not strictly applicable). The power spectrum of the first-story lateral deformation for the five-story brittle-walls system (5B), resistance ratio $R_2/R_1 = 2$, and initial natural period T = 0.67s, is shown in Fig. 5, where two dominant response frequencies appear: the first, equal to 3.1 rad/s, is associated to the excitation, while the second, approximately equal to 9.2 rad/sec, corresponds to the response. Thus, the dominat frequencies of response and excitation do not coincide in this case and therefore the response of the structure is small, as compared to the case where those frequencies coincide. (For instance, for R_2/R_1 = 1.2 those frequencies are very similar, as Fig. 6 indicates).

Similar results were obtained from the analysis of twelve-story structures with both types of walls and several resistance ratios R_2/R_1. A more detailed study of these cases is described in Ref. 2.

DISCUSSION AND CONCLUSIONS

The studies presented confirm the importance of the lengthening of the response period of structures (in this case weak-first-story systems) with natural periods shorter than those of the excitation, subjected to narrow-band earthquakes. They also show the preponderant role played by the hysteretic damping supplied by the walls. This became evident during the September 1985 earthquake in Mexico City, not only in weak-first-story buildings, but also in more general types of structures with fundamental vibration periods shorter than, but close to, 2s.

In the cases described in this study the lengthening of the dominant period of the structural response is produced mainly by yielding or failure of the walls. The latter totally disappear when their lateral deformation equals twice that corresponding to yielding (obviously, this is more likely to take place when the ratio R_2/R_1 is small), leading to the situation that the structure responds with a dominant period closer to that of the excitation. This gives place to amplification of the dynamic response. On the other hand, if the walls are ductile and their deformations reach their yield value, the period of the structural response becomes longer, and may become equal to that of the excitation. However, the structural response may be reduced due to the hysteretic dissipation of energy that takes place at the walls. If is not clear under what conditions the latter effect compensates the tendency for amplification of structural response associated with the coincidence of the dominant response periods with those of the excitation, but it can be stated that not all weak-story buildings are condemned to suffer excessive deformations at that story under the action of a severe narrow band earthquake, although the caracteristics of the structures that guarantee adequate behavior are still to be identified. On account of the wide uncertainties in our knowledge about the behavior of structural members and systems (Ref. 3), their mathematical modeling, and the estimates of seismic hazard at a specific site, it is very difficult to predict with enough confidence the conditions under which a weak-first-story construction will survive a high-intensity earthquake, unless it is designed for very high lateral forces (Ref. 2).

It is concluded that in order to make realistic estimates of the dynamic response of a structure with natural period moderately shorter than the dominant period of the excitation (narrow band earthquake) it is necessary to carry out a non-linear, step-by-step, dynamic response analysis, including a realistic model of the behavior of structural members. Because the response is very sensitive to the detailed characteristics of the force-deflection properties of elements and to the peculiarities of the structural scheme adopted, the results of over-simplified models may be misleading. For the same reason, the results of detailed non-linear response studies must be interpreted with caution, and the variability of the response with respect to reasonable variations in the deformation characteristics of the structural members has to be accounted for.

ACKNOWLEDGEMENTS

The authors are thankful to L Esteva for his critical revision of the manuscript and valuable comments. This study was partially sponsored by the National Council of Science and Technology and by México's Federal District Department.

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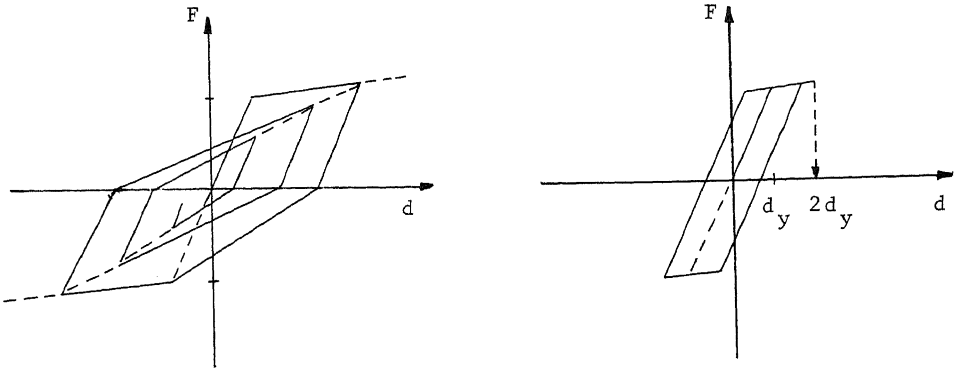

Fig 1. Force-deformation relations of infill walls

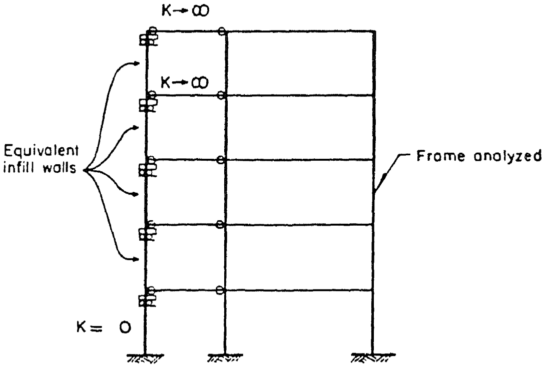

Fig 2. Equivalent frame including walls

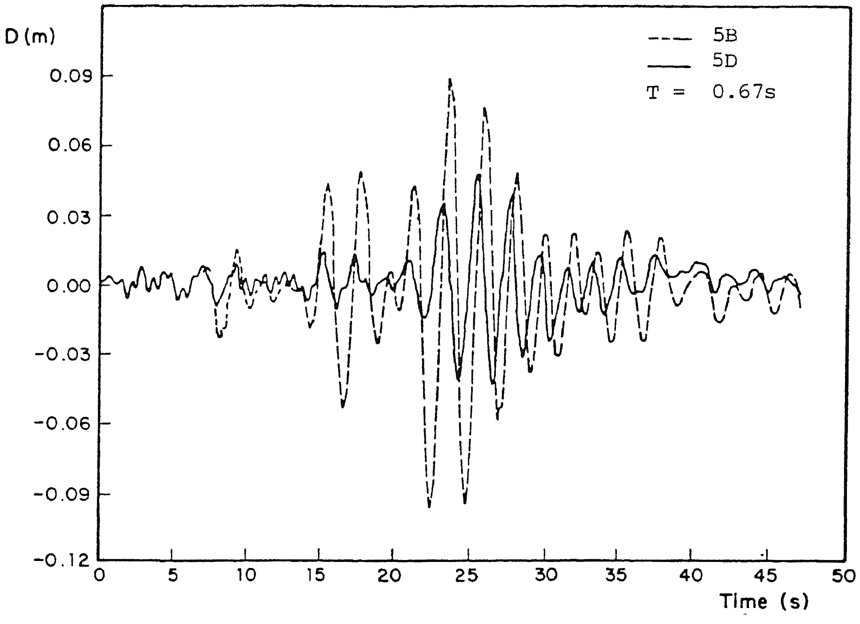

Fig 3. Time displacement histories of first floor, $K_2/K_1 = 4$, $R_2/R_1 = 1.2$

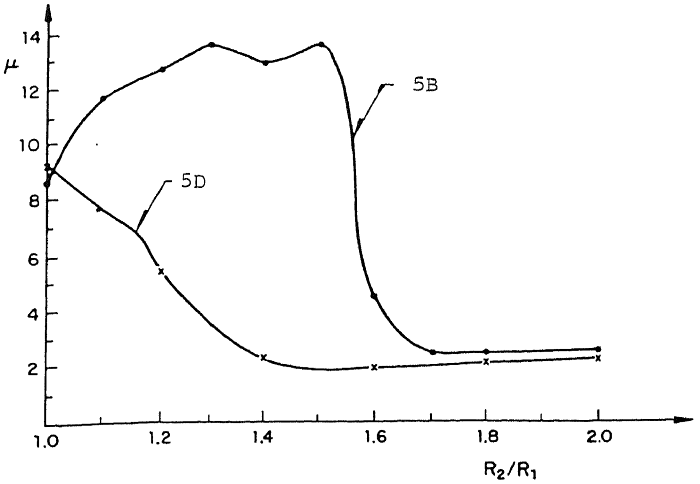

Fig 4. First story displacement ductility demands, T = 0.67s
$K_2/K_1 = 4$, $C_s = 0.06$

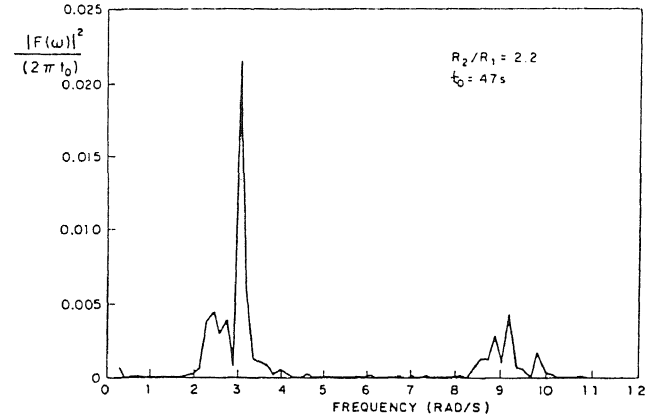

Fig 5. Spectral density of first floor displacements, $T = 0.67s$, $K_2/K_1 = 4$, case 5B

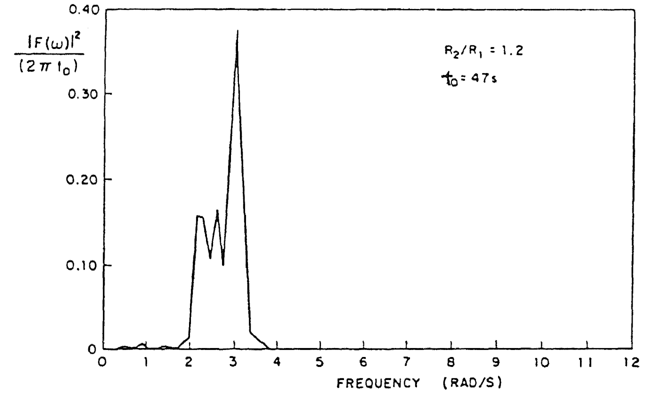

Fig 6. Spectral density of first floor displacements, $T = 0.67s$, $K_2/K_1 = 4$, case 5B