SOIL-STRUCTURE INTERACTION EFFECTS IN THE CARACAS EARTHQUAKE OF 1967

by

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SYNOPSIS

The observed relationship between the intensity of structural damage and soil depth in the Caracas earthquake is presented, together with the general dynamic characteristics of the soil deposits underlying the city. Analytical studies taking into account the overall influence of the soil on building response are shown to give patterns of base shear, base moment and damage potential, which are in reasonable accord with field observations.

INTRODUCTION

The Caracas earthquake of June 29, 1967 caused surprisingly heavy damage to multi-story buildings. Although the magnitude of the earthquake was only about 6.3 and its epicenter was located about 35 miles west of Caracas, the shaking caused the collapse of four 10 to 12 story apartment buildings in Caracas with the loss of over 200 lives and many other structures suffered structural damage and severe architectural damage. While no records of ground accelerations were made during the earthquake it has been estimated that the maximum ground acceleration was of the order of 0.06 to 0.08g in east Caracas (Sozen et al., 1968); observations from similar earthquakes would indicate that the maximum accelerations in rock would be about half of these values.

DAMAGE DISTRIBUTION

Following the earthquake a detailed study of the locations of damaged and undamaged buildings of different types was made by the Venezuelan Presidential Commission for Investigation of the Earthquake, together with a study of soil depths throughout the city. Since the soils underlying Caracas are everywhere very similar in dynamic characteristics, the depth of soil was essentially the only significant variable from one site to another. With the aid of this information, it was possible to investigate the relationship between the structural damage intensity (defined as the ratio of the number of buildings suffering structural damage to the total number of buildings in any zone) and the depth of soil in different zones of the city. The results of this investigation (Seed et al., 1972) are presented in Fig. 1. It is readily apparent that for soil depths less than 100 meters, the damage intensity was highest for 5 to 9 story buildings but for soil depths over 150 meters, the structural damage intensity was about eight times higher for buildings with over 14 stories

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than for structures in the 5 to 9 story range. The results shown in Fig. 1 indicate a strong influence of soil conditions on structural performance during the earthquake and accordingly analytical studies have been made to determine whether such effects can be anticipated as a result of soil-structure interaction effects.

SOIL CONDITIONS

Representative soil conditions for the city of Caracas, determined by seismic surveys, are shown in Fig. 1. In general the soils consist of sand and gravel with a clay binder, becoming increasingly dense with depth. Average values of shear wave velocity at different depths are shown in the figure, providing a basis for determining the shear moduli of the soils, for very small strain conditions, at various depths.

In evaluating the seismic response of soil deposits, it is necessary to take into account the non-linear stress-strain relationships of the soils, which cause the effective shear moduli and damping ratios to vary with strain. Studies of the relationships between moduli, damping ratios and shear strain for a large number of cohesionless soils have led to the average relationships shown in Fig. 2. These relationships may therefore be used, with the data shown in Fig. 1, to determine shear moduli and damping ratios for the Caracas soils at all levels of shear strain.

STRUCTURAL RESPONSE DURING THE EARTHQUAKE

In order to analyze the response of structures on different depths of soil during the earthquake, computations were made for the soil-structure system shown in Fig. 1. The motions in the base rock were considered to have a maximum acceleration of 0.03g and a time history similar to the Taft record of the 1952 Kern County, California, earthquake. Buildings were considered to have structural characteristics similar to those of the Charaima Building (Penzien et al., 1970) with 5 percent damping. An iterative procedure was used to determine the moduli and damping ratios for the soil, values being adjusted until they were compatible with the data shown in Figs. 1 and 2. Typical results for a 12-story structure having a period of 1.65 seconds constructed on different depths of soil are shown in Fig. 3. It may be seen that although the maximum ground surface acceleration does not vary significantly for different soil depths, there is a marked increase in both the maximum base shear (V_{max}) and the maximum base moment (M_{max}) when soil depths exceed about 150 meters. This is in good accord with the damage data shown in Fig. 1.

Similar computations were made for structures having the following periods:

Group 1 (5 to 9 story buildings): T_1 = 0.39, 0.51, 0.65 sec
Group 2 (10 to 14 story buildings): T_1 = 0.76, 0.90, 1.05, 1.18 sec
Group 3 (15 to 19 story buildings): T_1 = 1.25, 1.45, 1.65 sec.

For each structure, the damage potential index, F_r, was then computed from the expression (Seed, 1969):

$$F_r = \frac{V_{max} \cdot T}{W \cdot C}$$

where T = fundamental period of building
W = weight of building
C = design lateral force coefficient

Average values of F_r for different soil depths were then determined for structures within the three groups listed above. Based on measured values of building periods in Caracas, these period ranges represent average values for buildings with story heights of 5 to 9, 10 to 14 and 15 to 19 respectively. The resulting average values of damage potential index for the three story height ranges are plotted in Fig. 4. It may be seen that the general pattern of damage potential determined by the analysis including soil-structure interaction effects is very similar to that shown in Fig. 1. However analyses based on a ground surface motion corresponding to an arbitrary soil depth would not indicate the damage pattern caused by the earthquake.

CONCLUSION

Both field data and analytical studies have shown that soil-structure interaction effects had a large influence on the intensity of structural damage in Caracas in the 1967 earthquake. It should be noted however that the effects of physical interaction between buildings and soil for the types of structures involved has been shown by many investigators to be unlikely to exceed several tens of percent. Accordingly the large effects observed in Caracas would seem to be attributable primarily to the modification of ground surface motions by the different soil conditions, producing very strong responses when the response characteristics of a structure are similar to those of the deposit on which it is located. It may be concluded that consideration of these effects in seismic design is clearly desirable.

ACKNOWLEDGEMENT

The support of the National Science Foundation which sponsored the study described in the preceding pages, is gratefully acknowledged.

REFERENCES

Penzien, J., et al. (1970) "Seismic Analysis of the Charaima Building, Caraballeda, Venezuela," EERC Report No. 70-4, Earthquake Engineering Research Center, University of California, Berkeley, August (by Subcommittee of SEAONC Research Committee, J. Penzien, Chairman).

Seed, H. Bolton (1969) "The Influence of Local Soil Conditions on Earthquake Damage," Preprint of State-of-the-Art Lecture, Seventh International Conference on Soil Mechanics, Soil Dynamics Specialty Conference, Mexico City, August.

Seed, H. Bolton, Whitman, R. V., Dezfulian, Houshang, Dobry, Ricardo and Idriss, I. M. (1972) "Soil Conditions and Building Damage in 1967 Caracas Earthquake," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 98, No. SM8, Proc. Paper 9108, August, pp. 787-806.

Sozen, M. A., Jennings, P. C., Matthieson, R. B., Housner, G. W. and Newmark, N. M. (1968) "Engineering Report on the Caracas Earthquake of 29 July 1967," National Academy of Sciences, Washington, D. C.

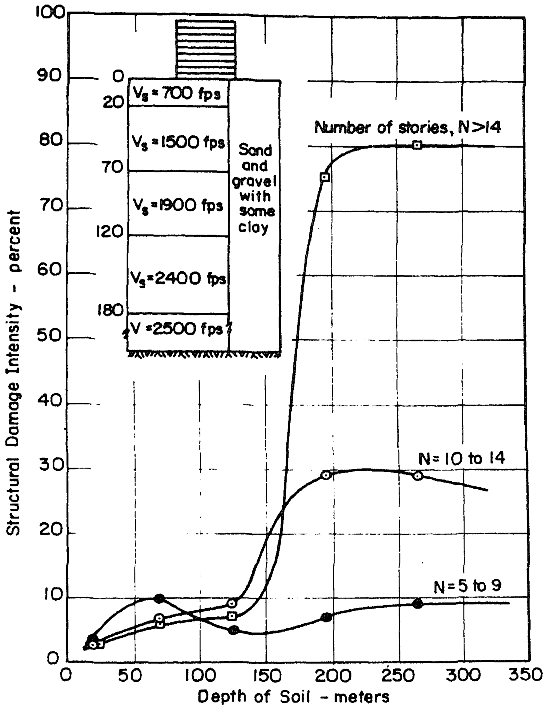

Fig. 1 RELATIONSHIP BETWEEN STRUCTURAL DAMAGE INTENSITY AND SOIL DEPTH IN CARACAS EARTHQUAKE, 1967

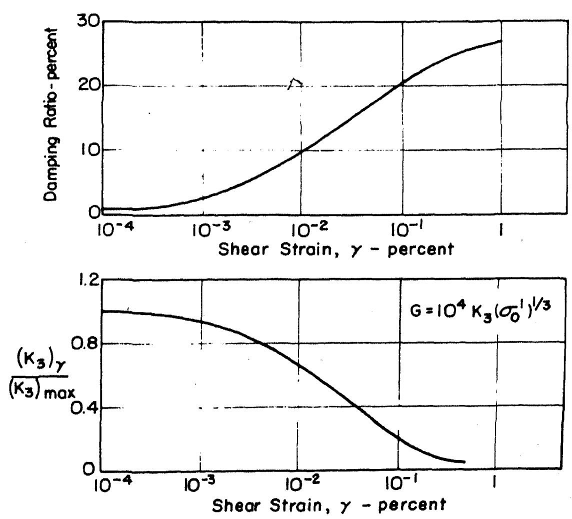

Fig. 2 AVERAGE SHEAR MODULI AND DAMPING CHARACTERISTICS FOR COHESIONLESS SOILS

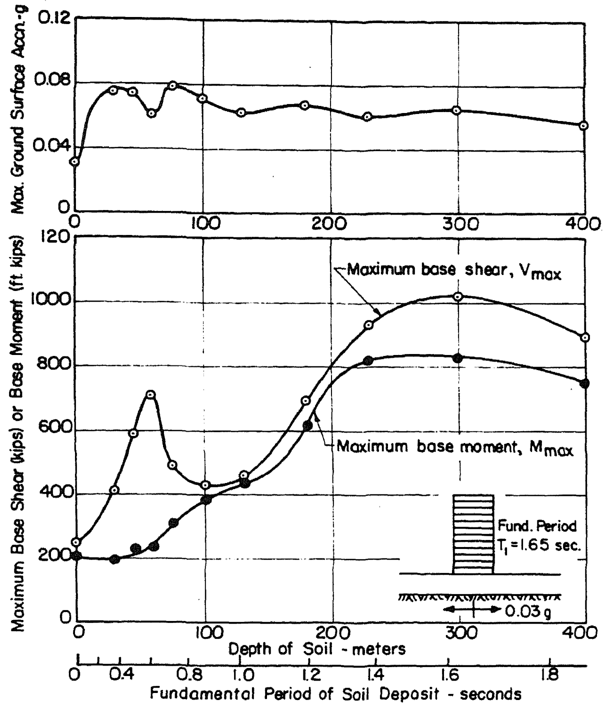

Fig. 3 COMPUTED RELATIONSHIP BETWEEN STRUCTURAL RESPONSE AND SOIL DEPTH FOR MULTI-STORY BUILDING (FUNDAMENTAL PERIOD = 1.65 SECONDS)

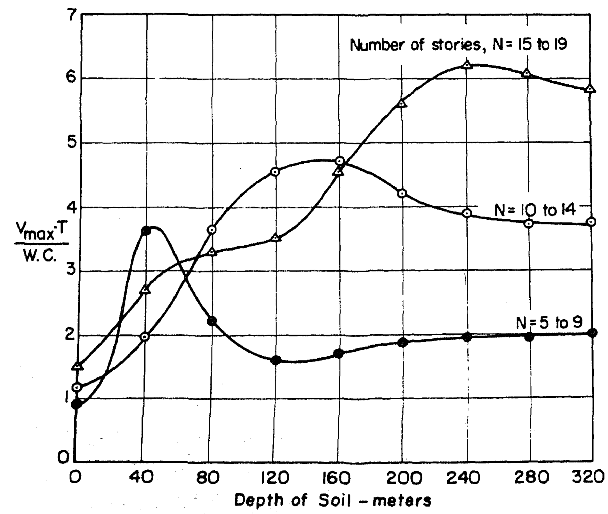

Fig. 4 COMPUTED RELATIONSHIP BETWEEN BUILDING DAMAGE POTENTIAL AND SOIL DEPTH IN CARACAS EARTHQUAKE, 1967

Session 6A: Paper no. 265 by H. Seed & J. Alonso

Discussion by: N. N. Ambraseys

I notice that your conclusions are based on two curious assumptions; that the maximum bedrock acceleration in Caracas was 7%g and that the time-history of the Caracas earthquake was similar to the Taft record.

How do you substantiate these assumptions? Do you think that your conclusions are more reliable than your assumptions?