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SYNOPSIS: The 1985 Michoacan earthquake caused extensive loss of life and severe damages. During the earthquake, the ground motions recorded at the soft clay sites were amplified by 8 to 50 times those at nearby rock sites. This study evaluates the factors influencing the seismic characteristics of the lakebed deposit in Mexico City. The essential components of response analysis are examined in both 1-D and 2-D soil systems.

The amplification of ground motion can be evaluated in both 1-D and 2-D analyses. Results show that the soil property has much greater influence than the control motion on the surface ground motion. Meanwhile, the amplification of ground motion is more pronounced in the 2-D system than in 1-D system. The two-dimensional effect also results in greater amplification in the region close to the edge of lakebed deposits.

INTRODUCTION

It has been recognized that local soil conditions impose significant effects on the amplitude and frequency characteristic of ground motion during an earthquake. The Michoacan earthquake of September 19, 1985 (M_s=8.1) caused extensive loss of life and severe damage in Mexico City even though the city is located 250 miles away from the epicenter. One of the most dramatic effects of soil conditions was the large amplification of ground motion. The peak ground accelerations recorded at soft clay sites are three to five times those recorded at nearby rock sites.

Mexico City is located on the edge of an old lakebed which is essentially filled with soft clay deposits. Mountains composed of volcanic materials are located on the west side of the city. During the earthquake, different intensities of shaking were observed in different parts of the city. It is interesting to notice that the area of severe building damage lies within two miles of the soft clay deposits boundary. In this area, the depth to the bottom of soft clay deposits, including the interbedded sand and silt thin layers, ranges from 80 feet to 140 feet. Buildings ranging from 8 to 15 stories suffered the greatest damage.

This study evaluates factors influencing the seismic characteristics of the lakebed deposits in Mexico City. Three essential components of dynamic response analysis including geometry of soil profile, soil property, and ground motion are carefully examined. Their effects on the amplification of surface ground motion are investigated analytically.

SOIL CONDITIONS IN MEXICO CITY AREA

Most of the geological information and subsoil characteristics of Mexico City area have been reported by Marsal and Mazari (1959), Romo et al. (1988), and other publications. In the lakebed area, a superficial layer of alluvial deposits with depth of a few feet is underlain by thick soft clay formations interbedded by thin sandy layers. Natural water content of the upper clay formation ranges from 100 percent to 500 percent while shear wave velocities range between 130 ft/sec and 300 ft/sec. The lower clay formation has relatively lower water content ranging from 50 percent to 300 percent, and higher shear wave velocities ranging between 300 ft/sec and 1100 ft/sec.

The depth to the bottom of the lower clay formation increases from the edge to the center of the lakebed to more than 250 feet. Underlying the lower clay formation there are thick formations of very stiff sand and gravel with shear wave velocity of 1500 ft/sec or greater. Due to its stiffness, this formation is usually considered as the base stratum for engineering purposes. The geotechnical information on the soil below this level is not as available as the data on overlying clay formations.

In this study, the soil deposit of the lakebed is considered extending vertically to a rigid base which is assumed to be 800 feet deep in the central portion of the basin. A simplified and smoothed two-dimensional soil profile is shown in Figure 1 that with a width of 30,000 feet at the

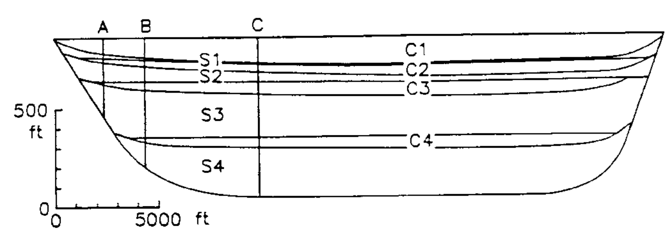

FIG. 1 Simplified and Smoothed Two-Dimensional Soil Profile for Lakebed Deposits in Mexico City Area

ground surface. On the basis of soil characteristics, the profile consists of four clay layers (C1, C2, C3, C4) and four sand and gravel layers (S1, S2, S3, S4). The shear wave velocity V_s and maximum shear modulus G_{max} assigned to each layer are listed on Table 1.

TABLE 1. Soil Properties of Each Layer in the Soil Profile

LAYER	γ (pcf)	G_{max} (ksf)	V_s (ft/s)
C1	75	40	131
S1	115	4348	1100
C2	86	1720	800
S2	117	6179	1300
C3	87	2665	990
S3	118	8859	1550
C4	91	3761	1150
S4	120	12150	1800

CONTROL MOTION AND DYNAMIC SOIL PROPERTY

As mentioned above, the severely damaged area during the Michoacan earthquake is adjacent to the edge of the lakebed. Therefore, this study focuses on the ground motion characteristic in the area close to the edge of the lakebed. Since the subsoil layers in this area are not infinitely laterally extended, a series of two-dimensional seismic response analyses are performed by using the finite element program FLUSH developed by Lysmer et al. (1975). For a better understanding of the effect of the geometry of soil profile on the ground motion, the analysis based on one-dimensional wave propagation theory (Schnabel et al., 1972) is used for a comparison.

Two ground motions of rock site are chosen as the base excitation motions in order to reveal the influence of incident ground motion. One motion (E1) is adopted from the S-N component of accelerogram recorded at CUMV site during the Michoacan earthquake. The other motion (E2) is artificially generated by an earthquake simulation program developed by Chang et al. (1985). Two rock site motions have similar magnitudes and maximum accelerations but they differ in the frequency contents as shown in Figure 2.

The nonlinear dynamic properties of soil are represented by the strain dependent shear modulus and damping ratio. For studying the effect of soil property on the ground motion, Figures 3 and 4 show two different sets of strain dependent dynamic properties for clay. The one (P1) shown in Figure 3 is modified after the results of studies on the Mexico City clay by Leon et al. (1974) and Romo and Jaime (1986). The other one (P2) shown in Figure 4 is modified after the typical strain dependent properties of ordinary clay presented by Seed and Idriss (1970). Th dynamic properties for sand and gravel in thi study are presented in Figure 5 (After Seed an Idriss, 1970).

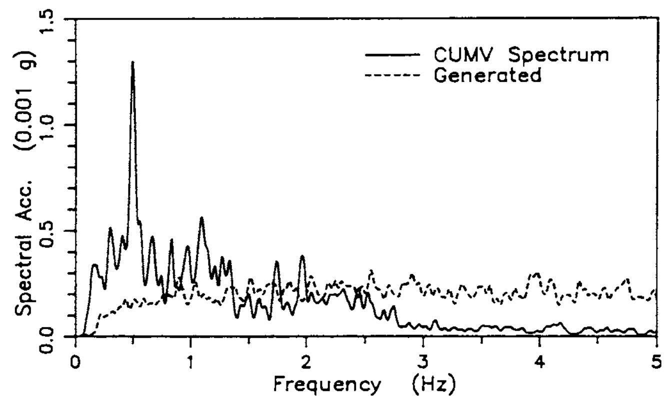

FIG. 2 Fourier Spectra of Base Excitatio Motions

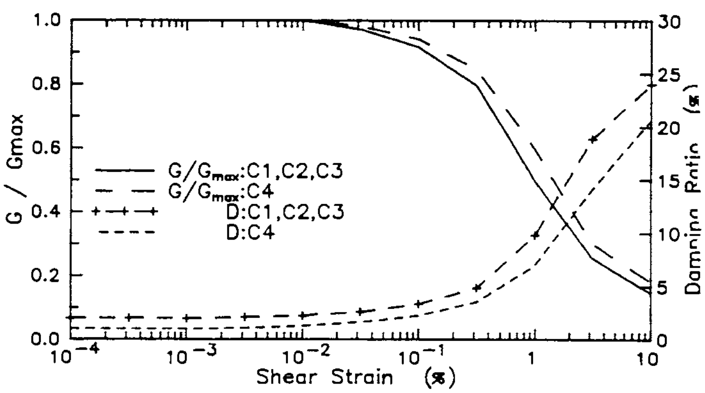

FIG. 3 Strain Dependent Shear Moduli and Dampinc Ratios for Mexico City Clay (P1) (After Leon et al.,1974, Romo and Jaime, 1986)

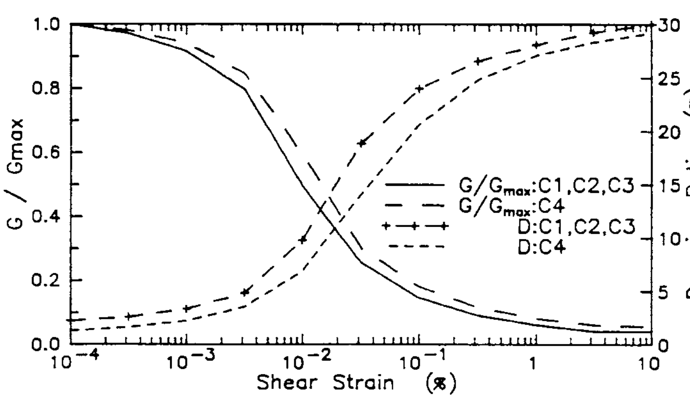

FIG. 4 Strain Dependent Shear Moduli and Damping Ratios for Ordinary Clay (P2) (After Seed and Idriss, 1970)

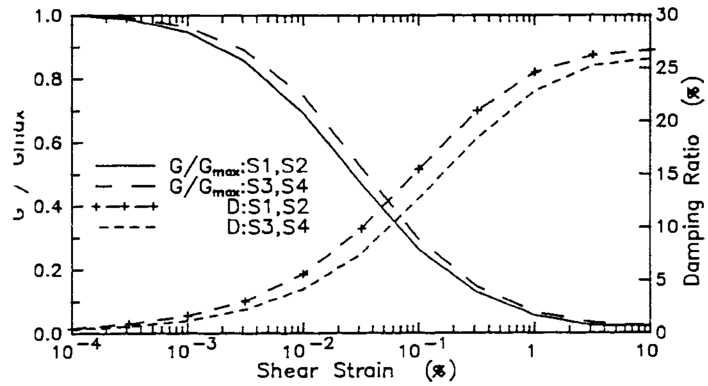

FIG. 5 Strain Dependent Shear Moduli and Damping Ratios for Sand and Gravel (After Seed and Idriss, 1970)

The seismic characteristics of the lakebed deposits are evaluated in four different cases. Case 1 simulates the ground motions in Mexico City during the Michoacan earthquake by using control motion E1 and clay properties P1 in a two-dimensional analysis. The second case also uses control motion E1 and clay properties P1 but simulates the ground motions along one-dimensional profiles. These 1-D profiles locate at 2400 ft, 4400 ft, and 10000 ft from the edge of lakebed and denoted as A, B, and C respectively in Figure 1. Case 3 uses the control motion E2 and clay properties P1 in a two-dimensional analysis. Case 4 uses the control motion E1 and clay properties P2 in a two-dimensional analysis.

EFFECTS OF GEOMETRY OF SOIL PROFILE

The analytical responses of surface ground motion at point B and the response spectrum of motion recorded at SCT site, a deep soft clay site, during the Michoacan earthquake are compared in Figure 6. Apparently, the responses from both two-dimensional (Case 1) and one-dimensional (Case 2) analyses are in close agreement in general trend with that of recorded motion. Both computed and recorded predominant periods are 2 seconds at point B. Since the analyses are not quite site specific and due to the variations in soil properties, the difference in peak spectral values is expected.

The peak ground acceleration recorded at CUMV site, a rock site, was 0.038 g during the Michoacan earthquake. With the same source of excitation, the peak ground accelerations at soft clay sites were 0.171 g at SCT site and 0.136 g at TLA site. Assuming the base of lakebed rigid, the ground motion was amplified significantly through the lakebed deposits.

The results of both 1-D and 2-D analyses provide the vertical variations of maximum accelerations (A_{max}) along the profiles A, B, and C, and Figure 7 shows the one for profile B. Starting with a value of 0.038 g at the rigid base, the A_{max} gradually increases with a minimum difference in Case 1 and Case 2 below a depth of 100 ft. When the ground shock propagates though the upper clay layer within top 100 ft, the amplification

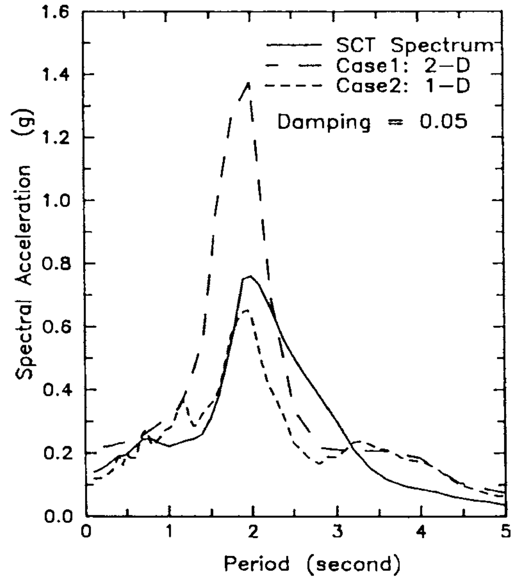

FIG. 6 Comparison in Response Spectra between Computed Motions at Point B and Recorded Motion at SCT site

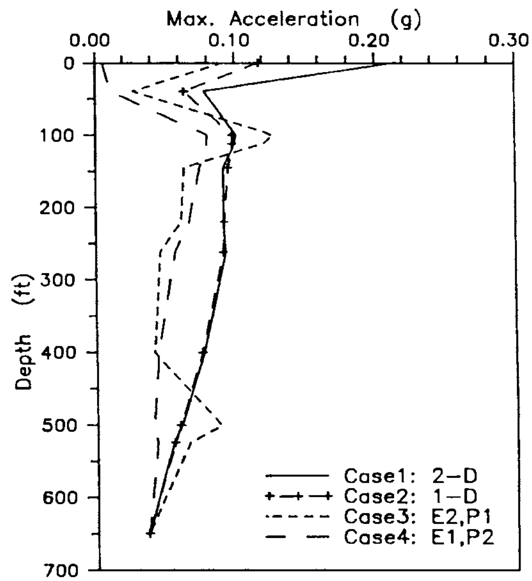

FIG. 7 Vertical Variations of Maximum Accelerations along Profile B

becomes obviously different in these two cases. The computed A_{max} at point B is 0.216 g from 2-D analysis and 0.118 g from 1-D analysis.

Similar relationships of vertical A_{max} variations between 1-D and 2-D approaches are also found in profiles A and C. They both increase gradually in the soil deposit between base and the bottom of upper clay layer. However, they differ in the amplification characteristics within the upper clay layer. It implies that some amplification effects of the soft clay shown in 2-D approach may not be seen in 1-D approach.

Figure 8 presents the computed maximum accelerations at both the bottom and top of upper clay layer from 2-D and 1-D approaches. Within a distance of about one mile from the edge of lakebed, the soft clay amplifies the ground motions significantly, especially in the 2-D approach. Nevertheless, beyond the distance of one mile, the A_{max} is reduced through the soft clay layer in 2-D approach while it is still amplified along profile C in 1-D approach.

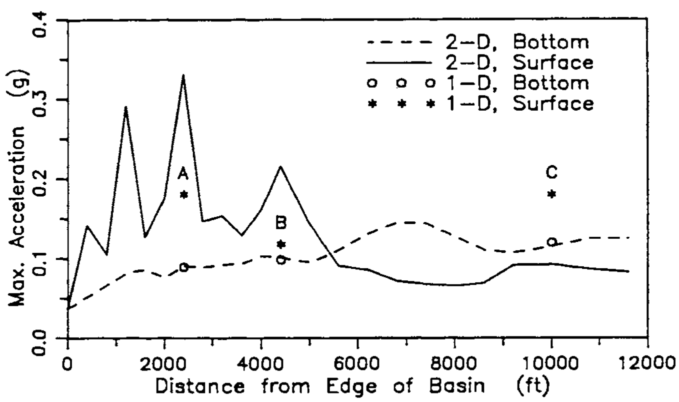

FIG. 8 Distributions of Changes in Maximum Accelerations Between the Bottom and Top of Upper Clay Layer

The difference in amplifications between two approaches disclosed here may be explained by the different geometries upon which their analyses are based. The effect of the edge boundary of soil profile and each subsoil layer on the amplification characteristics is taken into account in a 2-D analysis but not in a 1-D analysis. Therefore, a successful two-dimensional analysis can provide a better picture of the information on amplification of ground motion.

EFFECTS OF CONTROL MOTION AND SOIL PROPERTIES

On the basis of field records and analytical results, Seed et al. (1988) concluded that the results of analysis are very sensitive to small changes in either the soil properties or the control motions. Figure 9 illustrates the differences in responses of ground motion at point B due to the changes of base excitations (Case 3) or soil properties of clay (Case 4).

A base motion with different frequencies propagating through the same soil deposits as Case 1 to point B still shows a very distinct predominant period. However, its predominant period shifts from 2 seconds to 1.4 seconds and its spectral amplitudes reduces significantly. In the case of the same earthquake taking place in a different soil deposit, with thick layer of ordinary clay, the spectrum of motion at point B does not show any significant response.

The vertical variations of A_{max} along the profile B with different base excitation or dynamic soil properties have been shown in Figure 7. The changes in A_{max} with depth in Case 3 and Case 4 are not in the same pattern as that in Case 1. It may

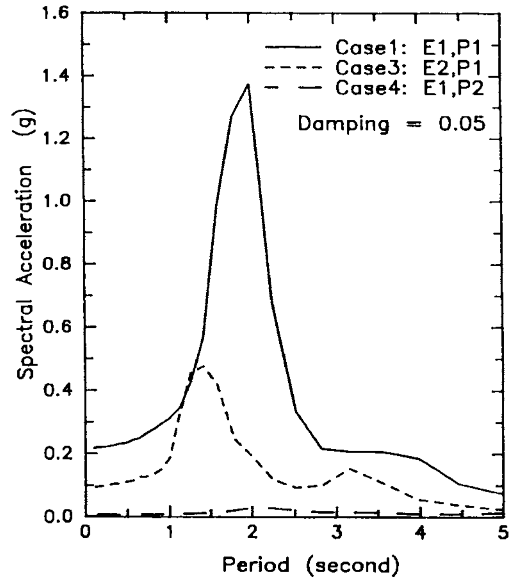

FIG. 9 Response Spectra of Computed Motion at Point B in Case 1, Case 3, and Case 4

be seen that the values of A_{max} decrease substantially in the upper clay layer, especially by changing the dynamic soil properties for clay.

The results of Case 3 and Case 4 show that the distributions of peak ground surface accelerations are not in the same pattern as Case 1 as shown in Figure 10. By changing the control motion, the amplifications of A_{max} are less significant and appear having periodic variation with the distance from the edge of lakebed. This special type of variation may be owing to the frequency characteristics of ground motions and the shape of base boundary. In the other case, with ordinary clay deposits, the peak ground surface accelerations always attenuate across the surface of lakebed deposits. Therefore, the dynamic soil properties of soft clay show more important influence on the amplification of ground motion.

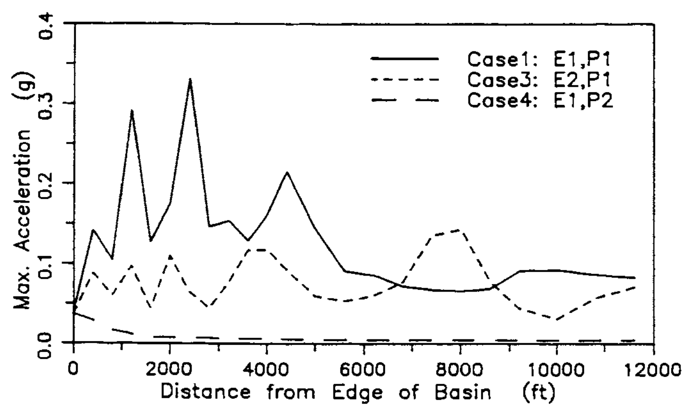

FIG. 10 Distributions of Peak Ground Surface Accelerations in Case 1, Case 2, and Case 3

'ONCLUSIONS

onclusions can be drawn for the results of these .nalyses as follows:

. The response characteristics of ground motion can be well simulated analytically by either the 1-D or 2-D approach although the amplitude may vary due to the effects of variations in soil properties.

.. The vertical variations of computed maximum acceleration from 1-D and 2-D analyses are in good agreement below the bottom of upper clay layer. However, the amplification of maximum acceleration within the upper clay layer is quite different.

3. Two-dimensional analysis takes account of the effect of edge boundary of soil profile and subsoil layers on the characteristics of amplification. Therefore, it is a better approach for investigating the ground motion amplification characteristics in a basin shaped soil deposit.

4. In the case where a ground motion with different frequency characteristics propagates through the same soil deposits, the ground surface motion still shows a distinct predominant frequency as well as a significant ground motion amplification.

5. The results of analysis using the same control motion indicates that a change in dynamic soil properties for soft clay deposits affects the frequency and amplification characteristics dramatically. It is reasonable to conclude that the soil properties of soft clay deposits play a more important role in the amplification of ground motion than the base excitations.

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