Areal response analysis in practice
Analyse de la réponse d'une zone dans la pratique

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SYNOPSIS: Mechanical and dynamic properties of Mexico City clays can be estimated through correlations with easily measured properties, like natural moisture and cone penetration resistance. If a reliable object motion at the base of the soft deposits can be established, site response analyses for the whole area of the lake zone can be performed. One such object motion is used as input in SHAKE; then results are gauged through the use of spectra resulting from registers of the 1985 quakes.

1 INTRODUCTION

If a given structure has a coupled period A (fig. 1) it is known that when an energetic quake hits it with several cycles of high accelerations, the structural stiffness degrades and the period increases. As the structure is sustaining damage the response escalates, with the possibility of reaching a maximum. On the other hand, another structure starting at point B will receive diminishing responses as damage accumulates, and its chances of reaching a maximum are nill. Since the compulsory seismic coefficient is equal for both structures, there is a definite technological advantage for the latter, because in the same environment it will have greater probabilities of surviving a strong quake. Of course there are other considerations aside coupled period that bear in the design of a structure, but this fact must be contemplated and gives rise to the need of analytically determining site response spectra.

2 OBJECT MOTION

According to Finn et al. (1987) " ... selecting suitable input motions for dynamic analysis is a very difficult task. " since quakes are most often recorded at the surface, and only infrequently at the base of the soils able to amplify motions. To compensate that, recording stations are usually sited at outcrops of the rocks that underlay those soils.

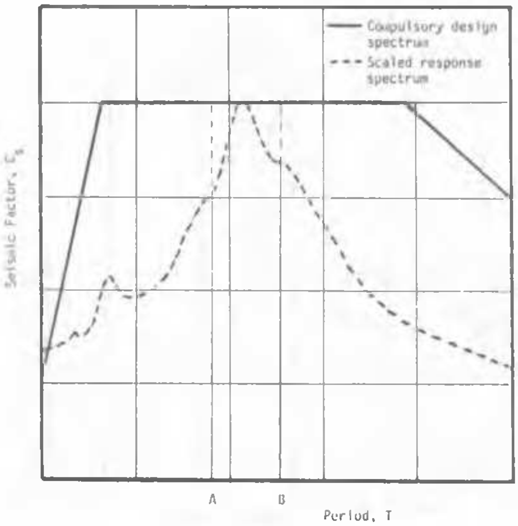

Figure 1. Use of response spectrum to add information to coded design spectrum.

To the South of Mexico City there is a young Basalt flow over wich the University City was built. There, exists an array of recording stations and Seed et al. (1987) used an average of the motions recorded during September 19, 1985 as the object motion in their analyses of the 1985 Mexican quakes. An alternate approach to get an object motion is using the register of the main event at sation TACY (fig. 2) that sits atop a tuff known locally as the Tarango formation. According to Mooser et al. (1986) below the lacustrine, soft, compressible, recent soils in the city there are alluvial and glacial deposits, named the deep deposits, resting over Tarango.

Tarango-like materials cover a large part of the sierras to the west of the city and are also found in the Cuernavaca Valley, to the south; and as far as the city of Pachuca, to the northeast. Rosenblueth and Elorduy (1969) found Tarango at 500 m depth in the heart of the city, at the Alameda park, and at 496 m in the housing complex of Tlatelolco, a few kilometers to the north. Relatively far from the eastern city outskirts, deep boring PP-1 was sunken to 2000 m depth (Marsal and Graue, 1969) where Tarango appeared at 516 m below the surface. PP-1 is the centerpiece of a seismic refraction prospection along three lines, with line 2 following a general W-E direction (fig. 2) and showing a refractor at close to 500 m in its entire length of 12 km, where P wave velocities change from 1800 to 2900 m/sec. It is then safe to assume that under a vast zone of the city Tarango remains at a fairly constant depth around 500 m.

Using the Rosenblueth-Elorduy stratigraphy at Alameda, the E-W component of the TACY register was convoluted with SHAKE (Schnabel et al., 1972) from 500 m depth to the contact of the soft soils with the deep deposits; and the object motion file TACY85.DEP obtained (Ellstein, 1988).

3 SOIL PROPERTIES

Most routine soil surveys reach the base of the soft soils, penetrating the upper part of the deep deposits, with at least the natural moisture profile and stratigraphy determined. Recently a continuous record of cone penetration resistances has also become a routine determination.

Marsal and Mazari (1959, 1987) have created a large data base, with which it is possible to estimate scores of mechanical properties for Mexico City soils through regression curves using the natural moisture as argument. This work led to the zonification of the city according to the compressibility of the soils found below the surface and three zones were mapped, with the lake zone being the most interesting from the point of view of number and importance of structures built. In turn the lake zone was subdivided in three groups according to the degree of

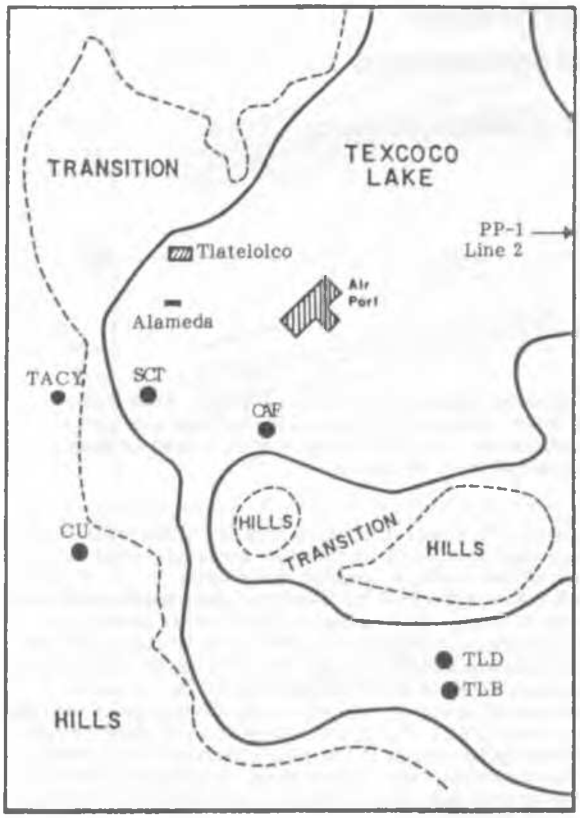

Fig. 2. Recording stations and deep boring sites (after Seed et al., 1987)

preconsolidation of the soils. Mechanical properties do vary from group to group, and regression curves exist for each of the groups. It is then possible from field and lab data to make accurate determinations of the thickness of strata and estimations of their densities.

Dynamic properties can not be directly found in the Marsal-Mazari data base, but a recent research effort by Jaime (1987) has yielded the necessary data for the lake zone. From his work three expressions can be extracted, relative to the three lake zone groups:

$V_s = 3.26 + 12.83q_c$ for Group 1
$V_s = 5.03 + 8.82q_c$ for Group 2
$V_s = 5.94 + 11.88q_c$ for Group 3

where V_s is the estimated shear wave velocity in m/sec and q_c the average cone resistance in kg/cm^2.

Following the visit of the British Earthquake Engineering Field Investigating Team that surveyed the city after the 1985 quake, Booth et al. (1986) among others, showed with a small series of tests performed at the University of Nottingham that the G-attenuation curves for Mexico City clays are different from those for normal clays. Jaime led a parallel but more ambitious investigation about this and both he and Seed et al. have published the pertinent curves for the lake zone.

4 RESPONSE SPECTRA

In order to find the reliability that can be assigned to TACY85.DEP as an object motion when used together with SHAKE, a calibration process was implemented using the spectra determined diectly from the recorded motions at several sites throughout the city (Mena et al., 1986; Carmona et al., 1987) as a basis for comparison. Stratigraphies, shear wave velocities, densities and G-attenuation curves reported in the works by Seed et al. and Jaime were also used as inputs.

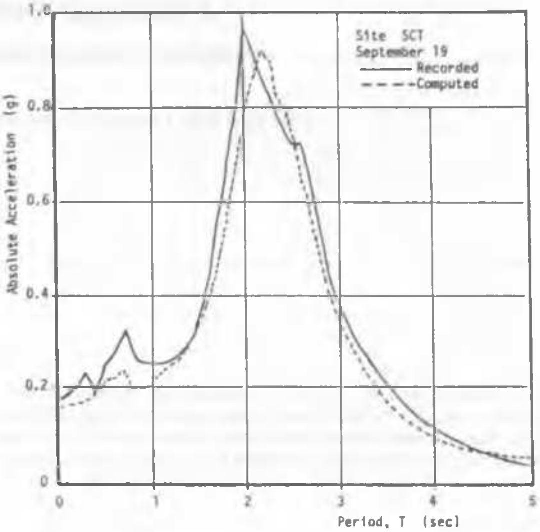

Figure 3. Comparison of recorded and computed spectra at SCT Site. Rating: Good.

Figs. 3 to 6 contain the recorded spectra at several stations as reported by Mena et al. for 5% damping, and also the computed spectra using the abovementioned input information. Results are mixed, and a summary is presented in Table I; rating the accuracy obtained for the prediction of the peak acceleration, the associated period, the width of the band where the response was strongest and the overall reliability of the computed spectra.

Table 1. Rating computed response spectra.

Site	Max. Accel. (g)	Period sec.	Band-width	All Around
SCT	0.92 (within 10%)	2.2 (within 10%)	good	good
CAF	0.45 (within 10%)	2.5 (within 20%)	fair	fair
TLD	0.53 (within 20%)	2.5 (within 30%)	poor	poor
TLB	0.91 (within 30%)	2.1 (within 5%)	fair	fair

Note:Time increments in TACY85.DEP changed to 0.025 sec.

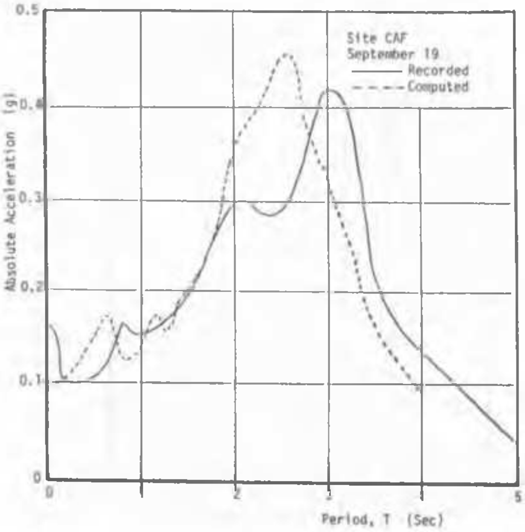

Figure 4. Comparison of recorded and computed spectra at CAF Site. Rating: Fair.

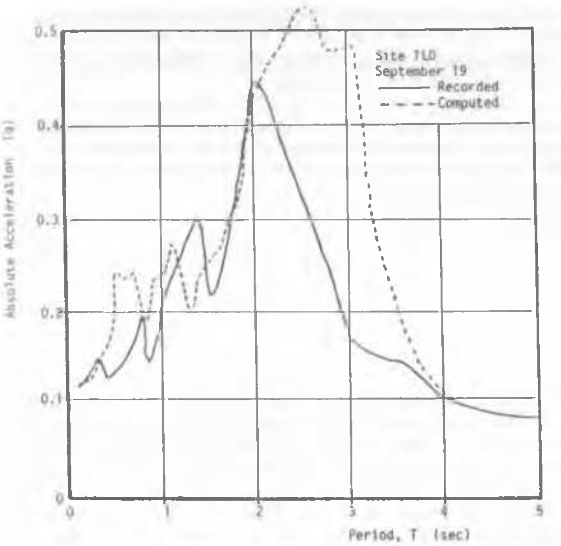

Figure 5. Comparison of recorded and computed spectra at TLD Site. **Rating:** Poor.

In order to count with some criterion to establish at least approximately the degree of reliability of the results, use is made of the envelope for response spectra published by Romo and Seed (1987) with the thickness of compressible soils as argument. The maximum spectral acceleration (A_m) and associated period (T_m) are expressed, according to that envelope, as functions of the depth for the deep deposits (D_d in m).

$$A_m = -1.25E-07D_d^5 + 2.66E-05D_d^4 - 2.12E-03D_d^3 + 7.83D_d^2 -1.31D_d + 8.55$$

$$T_m = -2.39E-07D_d^5 + 4.97E-05D_d^4 - 3.9E-03D_d^3 + 0.14D_d^3 -2.44D_d + 16.51$$

These parameters are then given a plus-minus latitude of 20% and a window formed. If the pair of values for the peak acceleration and associated period in the computed spectrum falls within the window, probabilities of having a fair to good spectrum are in turn good, because the bandwidth of maximum response is either adequately estimated or overestimated in the previously shown cases.

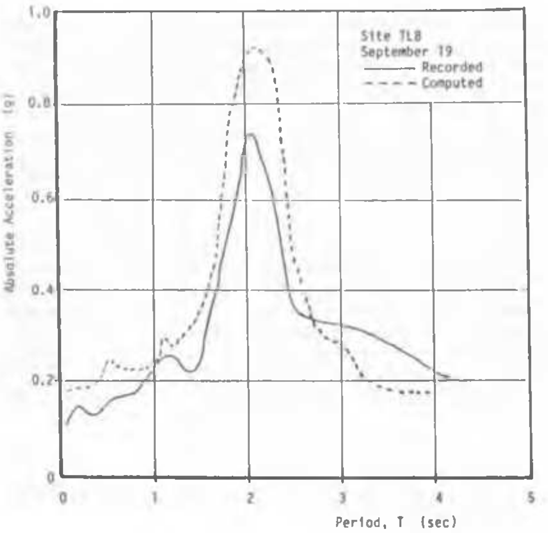

Figure 6. Comparison of recorded and computed spectra at TLB Site. Rating: Fair

5 FURTHER APPLICATIONS

To explore the usefulness of TACY85.DEP for quakes different from the September 19, records of the September 21 aftershock at TACY and CAF were used. The second quake was obviously milder than the main event and at TACY produced a maximum average acceleration of 13.9 gals, while the previous quake reached 33.8 gals. The ratio is of 0.41, similar to the ratio of 0.39 for the maximum amplitudes of the corresponding Fourier spectra. All the accelerations of TACY85.DEP were then scaled to 40% and the resulting object motion used again with the CAF stratigraphy and properties, giving the results labeled as 40% in fig. 7. It can be seen that the computed spectrum grossly overestimates the recorded one, and a possible reason might be, according to Singh et al. (1988) that " ...evidence suggests that the 19 September was about twice more energetic at around 2 sec. period than expected from scaling laws... ". According to this, TACY85.DEP was further scaled down to 20% of the original motion, but response was still overestimated. Finally a 10% version of TACY85.DEP was used and it reasonably reproduced the recorded spectrum. This might indicate that either the September 19 event was exceptionally energetic and that this quake may belong to a family of less than common quakes, or that its frequency content was quite different of September 21.

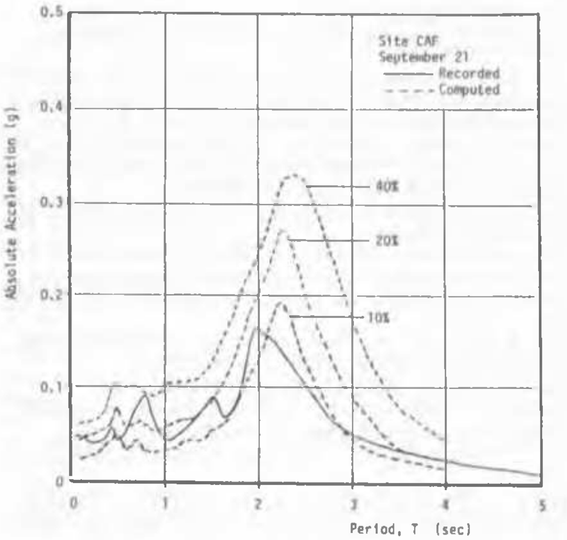

Figure 7. Use of TACY85.DEP to predict effects of strongest aftershock. Ordinary scaling criteria apparently not valid.

6 CONCLUSIONS

Site response spectra can be used together with compulsory design spectra, adding depth to the knowledge put at the disposal of the structural designer. The geotechnical man can give the former essential information to decide what stiffness to build into a particular structure during the design stage. This kind of collaboration leaves each specialist in his own field, but the overall design benefits considerably from taking into account the soil and its influence on the dynamic behavior of the structure.

Counting with statistically interpreted information regarding the mechanical and dynamic properties of the soils under Mexico City, gives a great advantage to the geotechnist, who can use that information for enhancement of field and lab data gathered for the dynamic analysis of large projects, or for making educated estimations for small ones on the basis of relatively simple site explorations. Large areas are now well known, and response spectra can be computed for them that fairly reproduce the free field response for energetic quakes stemming from the subduction zone.

For Mexico City, at least three other possible sources for strong quakes have been identifield besides the subduction zone (Rosenblueth et al., 1987). The September 21 quake cannot be fairly reproduced for the CAF site applying simple scaling laws, and if for a quake stemming from the same subduction zone, with a rupture area adjacent to that of September 19, TACY85.DEP is not valid already, it can be expected that it will not be adequate to model movements arising from rupture zones in other faults. Nonetheless, strong, destructive quakes in the city during this century have come from the subduction zone, and it can be presumed that if buildings are able to resist those, probably they will also have the strength to resist others coming from faults that are nearer but producing movements with less energy.

7 REFERENCES

Booth, E.D., Pappin, J.W., Mills, J.H., Degg, M.R. and Steedman, R.S. 1986. The Mexican Earthquake of 19 September 1985. EEFIT, SECED, London.

Carmona, C., Mena , E., Alcantara, L., Delgado, R., and Dominguez, O. 1987. Catálogo de Acelerogramas Procesados del Sismo del 19 de Septiembre de 1985, Parte II; Réplica del 21 de Septiembre en la Cd. de México. Series del Instituto de Ingeniería No. 503. UNAM, México.

Ellstein, A. 1988. SHAKE y el cono eléctrico en la Ciudad de México, Generación, Propagación y Efectos de Temblores. SMF-SMMS-UGM-SMIS, pp 113-117.

Finn, W.D.L., Yogendrakumar, M. and Nichols, A. 1987. Seismic response analysis: Prediction and performance. Prediction and Performance in Geotechnical Engineering; Joshi, R. C. and Griffiths, F. J., Eds. University of Calgary, Balkema, pp 39-50.

Jaime, A. 1987. Características Dinámicas de la Arcilla del Valle de México. Doctoral Thesis, UNAM, México.

Marsal, R. J. and Mazari, M. 1959. El Subsuelo de la Ciudad de México. UNAM, México.

Marsal, R. J. and Mazari, M. 1987. El Subsuelo de la Ciudad de México; Parte D; Variación de Propiedades Mecánicas con la Profundidad. Series del Instituto de Ingeniería No. 505, UNAM México.

Marsal, R. J. and Graue, R. 1969. The subsoil of Lake Texcoco, Vol. Nabor Carrillo, SHCP, México, pp 167-202.

Mena, E., Carmona, C., Delgado, R., Alcantara, L. and Dominguez, O. 1986. Catálogo de Acelerogramas Procesados del Sismo del 19 de Septiembre de 1985, Parte I; Cd. de México. Series del Instituto de Ingeniería No. 479, UNAM, México.

Mooser, F., Tamez, E., Santoyo, E., Holguín, E. and Gutierrez, C. 1986. Características Geológicas y Geotécnicas del Valle de México. COVITUR, México.

Rosenblueth, E. and Elorduy, J. 1969. Characteristics of earthquakes on Mexico City clay. Vol. Nabor Carrillo, SHCP, México, pp 287-328.

Rosenblueth, E., Singh, S.K., Ordaz, M. and Sanchez-Sesma, F.J. 1987. Espectros de diseño para el Distrito Federal. Memorias del VII Congreso Nacional de Ingeniería Sísmica. SMIS, Querétaro, pp A-1, A-17.

Romo, M.P. and Seed, H.B. 1987. Analytical modelling of dynamic soil response in the Mexico earthquake of Sept. 19, 1985. The Mexico Earthquakes - 1985. ASCE, N.Y. pp 148-162

Seed, H. B., Romo, M.P., Sun, J., Jaime, J. and Lysmer, J. 1987. Relationships Between Soil Conditions and Earthquake Ground Motions in Mexico City in the Earthquake of September 19, 1985. Report UCB/EERC-87/15, University of California, Berkeley.

Schnabel, P. B., Lysmer, J. and Seed, H.B. 1972. SHAKE: A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites. Report No. EERC/72-12, University of California, Berkeley.

Singh, S.K., Mena, E. and Castro, R. 1988. Some aspects of source characteristics of the 19 September 1985 Michoacan earthquake and ground motion amplification in and near Mexico City from strong motion data. Bull. Seism. Soc. Am. Vol. 78 No. 2, pp 451-477.