

Geotechnical aspects for the microzonation of Acapulco

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ABSTRACT: The building code for Acapulco was recently updated. To this end, a series of studies was performed involving the reassessment of local seismicity, attenuation laws, and local site effects. Also, a reevaluation of geological and geotechnical information was in order. In this paper we focus mainly on aspects related to the influence of local geotechnical conditions on the definition of seismic microzones and design spectra for Acapulco. A parametric study provided insight into the effects of soil-structure interaction in typical high rise structures.

1. INTRODUCTION: LOCAL SEISMICITY

Recent geological surveys revealed that there are no active faults within Acapulco or its environs (Mooser and Montiel, 1989). The relevant sources of seismic activity are the subduction of the Cocos Plate below the North American Plate and the normal faulting of the subducted Cocos Plate (Ordaz et al, 1989).

Seismic activity in the Mexican Pacific coast has been monitored over the last few decades with the Guerrero Accelerographic Array, a network comprising 30 strong motion recording stations. Data provided by this network allowed seismologists to identify a seismic gap off the coast of Guerrero; when the energy accumulated at the Guerrero Gap is released, a large magnitude earthquake can occur ($M_s > 8.0$) with a probability higher than 0.6, within the next few decades (Singh et al, 1982). These conditions have a major influence on the present seismicity in and around Acapulco and the design spectrum for rigid ground shown in Fig 1 was defined taking all of them into account as well as attenuation laws derived *ex professo* (Ordaz et al, 1989). In what follows, we discuss some of the studies made for deriving design spectra for sites having stratified soils.

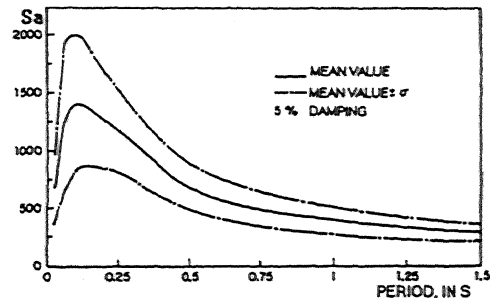


Figure 1. Design spectrum for hard soil in Acapulco. S_a is the spectral acceleration in gals.

2. SOIL CONDITIONS IN ACAPULCO

Acapulco has grown considerably over the past few decades. Urbanization has extended well outside Acapulco Bay. Accordingly, different geotechnical environments must be dealt with in defining general soil conditions in the Port. Geotechnical information from 227 soundings was analysed in order to produce the map of geotechnical zones given in Fig 2 (Ovando et al, 1989). According to consistency and soil type as well as to the sort of geotechnical problems found, firm, medium and soft soils were assigned to Zones I, II and III respectively.

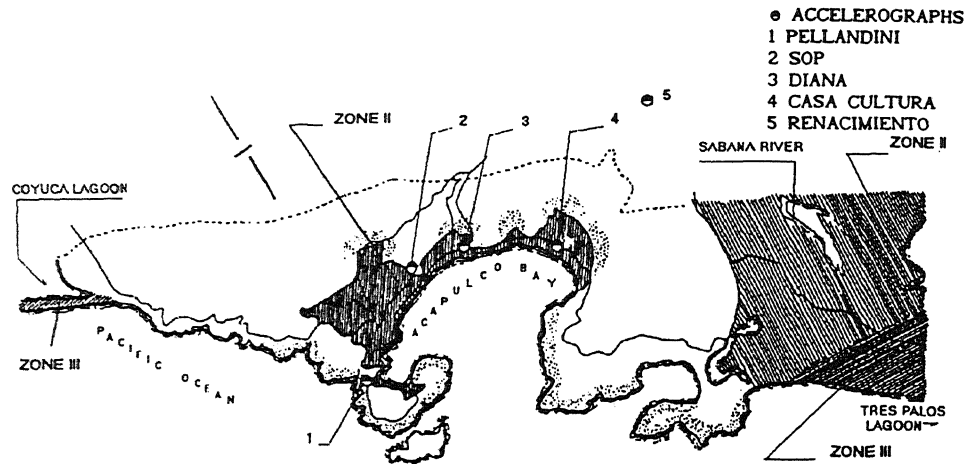


Figure 2. Geotechnical zones and accelerographic array in Acapulco.

2.1 Soils around Acapulco Bay

The bay zone concentrates the larger and most important structures in Acapulco. The bay is surrounded by granitic massifs and many of the soils there were formed by the decomposition of these rocks. Soil depths in this zone vary considerably, even over a few meters; from, say, a couple of meters to more than 60, according to Mooser and Montiel (1989). The deposition of soils was influenced by the transportation of material through the fluvial system that drains the bay. Organic lacustrine clay deposits having depths of 2 to 5 m are also found, interspersed with silty sands and low plasticity residual clays. In the upper parts, generally having very steep slopes, granite predominates. Soils in the lower parts were classified as belonging to Zone II—slightly compressible ground—whereas the higher parts all belong to Zone I, firm to very firm ground.

2.2 Soils in lagoon banks

Urban development has reached the banks that enclose the lagoons of Tres Palos and Coyuca (see Fig 2). Soils in the banks were deposited by eolic and marine transportation and are constituted by fine and very fine silty or clayey sand which can be very loose over the first three meters. Thereafter, soils have medium to high compacity. The depth of these deposits is not known but it is

larger than 20 m. Soils in the banks, softer than in the bay, were classified as belonging to Zone III.

2.3 Sabana River margins

Soils along the Sabana River are fine to medium sands deposited in depths larger than 10 m underlain by granites of varying ages and qualities, as inferred from seismic refraction soundings. Other geophysical studies suggest that towards the delta, loose saturated sands (liquefaction prone) may exist. Soils in the delta were included within Zone III and those in the upper parts within Zone II.

All other soils were included in Zone I, firm ground, and have a small crust of residual soil (up to some three meters) underlain by granite.

3. DYNAMIC SOIL PROPERTIES

For defining seismic microzones, dynamic soil properties must ideally be known in each of the geotechnical zones. Further, since seismic response of soil deposits also depends on boundary conditions, their geometry would also need to be specified. Such level of detail can seldom be achieved in most practical situations. In broad regional studies it is even more difficult to do so. In Acapulco, in lieu of other experimental data, average dynamic shear wave velocities, \bar{V}_s , were derived from local dominant periods, T_0 , and

soil depths, H, by means of the elastic relationship:

$$\bar{V}_s = \frac{4H}{T_0} \quad (1)$$

Local dominant periods were obtained from ambient vibration measurements and from the records of several small earthquakes that occurred at the time of the study (Gutiérrez et al, 1989). Depths of soil deposits were taken directly from data obtained from borings. In sites where H remained unknown, the Coyuca and Tres Palos sandy banks, for instance, the significant depth was taken to be H. The significant depth is the value of H required for $\bar{V}_s \geq 700$ m/s since for shear wave velocities having at least this value, the soil below can be assumed to be rigid in site response studies, without incurring in much error (Romo, 1989; Ordaz et al, 1989).

From the analysis of the geotechnical information and the data obtained from the ambient vibration study, it was concluded that average shear wave velocities ranged between 150 and 700 m/s. It was also established that dominant periods were less than 1 s. The situation $T_0 \geq 1$ s could not be ruled out but, given the shape of the response spectrum in which energy concentrates at far lower periods, setting the maximum period at 1 s is not critical.

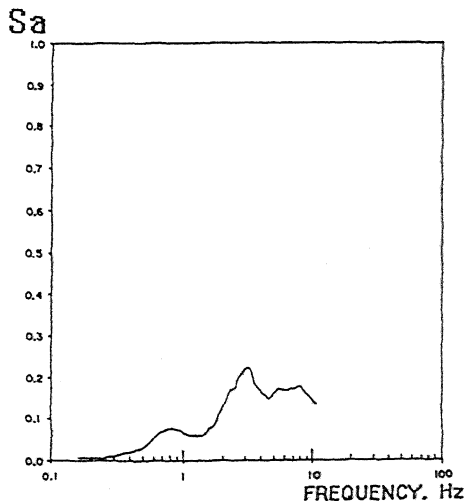


Figure 3. Response spectrum at the Pellandini Station, April 25, 1989. S_a is the spectral ordinate in g's.

4. SITE SPECIFIC SPECTRA

Having set the limits for the values of periods and shear wave velocities, local amplification studies were performed at several sites having typical stratigraphies which were modeled on the basis of average dynamic properties, obtained as described before.

The analyses were carried out using a finite element program that uses a one dimensional wave propagation model (Romo, 1990); linear elastic properties and constant damping values were assumed at this stage of the study. One dimensional models have proven to be quite reliable when applied in other geotechnical environments like Mexico City, for example (Romo and Seed, 1986). In the case of Acapulco, its validity needed to be asserted. On April 29, 1989 an earthquake, $M_s = 6.8$, occurred 50 km Southwest of Acapulco and was recorded by the local accelerographic network (see Fig 1). Thus, data were available for calibrating the model and the simplifying assumptions in regard to stratigraphy.

The acceleration record obtained at the Pellandini Station which lies on a granitic outcrop (see Fig 2) was used as input motion in the response analyses of sites having accelerographic stations within the bay area (Zone II). Average response spectra obtained from measured and computed surface motions are given in Figs 3 to 7. The following can be extracted

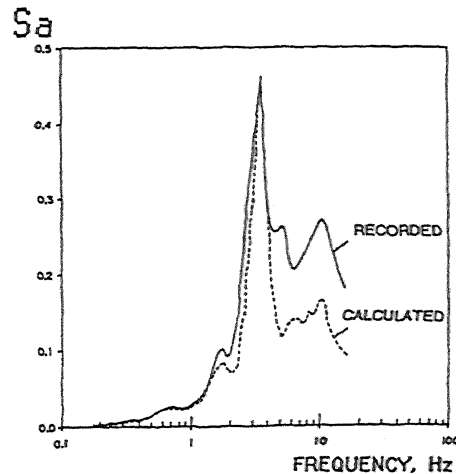


Figure 4. Response spectrum at the Renacimiento Station, April 25, 1989. S_a is the spectral ordinate in g's.

from these results:

Dominant frequencies obtained from predicted spectra match those obtained from recorded accelerographs. Spectral ordinates obtained from calculated surficial motions tend to underestimate those obtained from recorded accelerographs at frequencies higher than about 5 Hz, with the exception of station SOP which has a dominant frequency of about 10 Hz. In this station and in the Casa de la Cultura, spectral ordinates from the computed motions at the dominant frequency are considerably larger than the "measured" ones. Also, note that despite the fact that all the stations are contained within one geotechnical zone, Zone II, the range of measured site dominant frequencies is rather large.

From the above, one concludes that the model is not adequate for predicting spectral ordinates at high frequencies; say, higher than 10 Hz. For practical purposes this does not appear to be too restrictive given the range of likely structural periods. The overshooting of the calculated spectra at stations SOP and Casa de la Cultura at the sites' dominant period is by far more critical. However, from the engineering point of view, it can be concluded that the simplified one dimensional model yields "safe" predictions of the response spectra at or around any site's natural period, albeit, its results can be very conservative. In order to achieve better general agreement between the observed and predicted spectra a more refined model would have to be used. Given the magnitude of calculated and "measured" spectral ordinates it appears that nonlinear effects in the soils stress-strain relationships might play the most significant role, especially bearing in mind that the postulated design spectra for firm ground has very high ordinates (maximum ground acceleration ≈ 0.45 g), as may be seen in Fig 1. Also, lateral irregularities as well as topographic and three dimensional effects may not be negligible.

5. DESIGN SPECTRA

To take into account all of the factors involved in the seismic response of the soils in Acapulco is an exceedingly difficult task which lies outside the scope of this study.

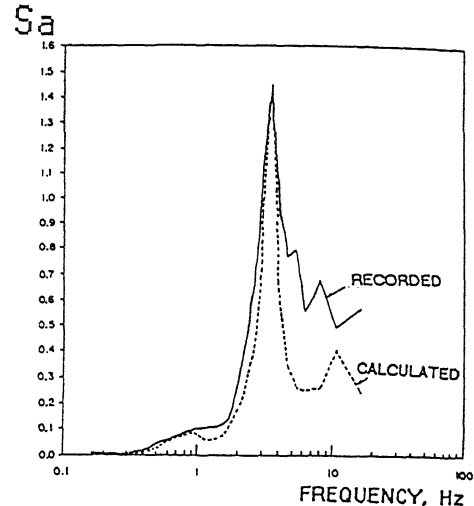


Figure 5. Response spectrum at the Diana Station, April 25, 1989. S_a is the spectral ordinate in g's.

Nevertheless, the effect of nonlinear soil behaviour was addressed introducing linearly equivalent stress-strain relationships (Seed and Idriss, 1969).

To obtain specific site spectra for design purposes, typical representative stratigraphies from Zones II and III were analysed. Dynamic soil properties (\bar{V}_s and damping ratio) and soil depths were varied in order to account for the diversity of dominant periods measured during the ambient vibration study at each of the geotechnical zones. Lacking experimental data, Seed and Idriss's (1970) normalized curves for specifying strain dependence of the soils' shear moduli and damping ratios were used. Input motions applied at the base of the deposits were defined by means of the design spectra for firm ground (Fig 1).

Results, given in terms of expected response spectra, are shown in Figs 8 and 9 for Zones II and III respectively. It is interesting to compare these spectra with the spectrum for firm ground. For periods lower than about 0.5 s soil deamplifies seismic movements whereas amplification is evident at periods ranging between 0.75 and 1.5 s; spectral amplitudes are roughly equal for larger periods. The smoothed envelopes shown in Figs 8 and 9 can be used as design spectra for practical purposes and are quite similar to the ones put forth by Ordaz et al (1989).

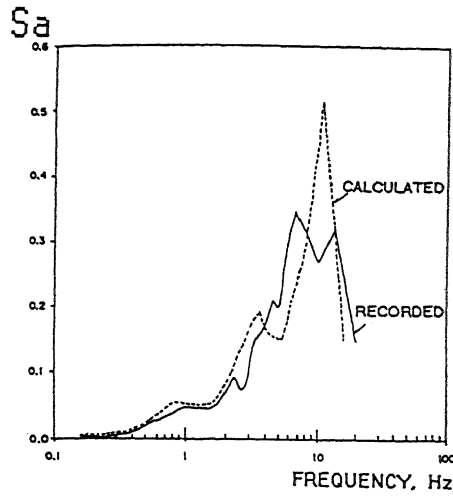


Figure 6. Response spectrum at the SOP Station, April 25, 1989. S_a is the spectral ordinate in g's.

6. SOIL-STRUCTURE INTERACTION

The design spectra given before pose high demands on most structures, especially high rise buildings, even allowing for reductions on account of ductility or other structural nonlinearities. The code, however, allows for the use of base or floor spectra modified by soil-structure interaction. A parametric study was carried out in order to gain insight into the effects of soil structure-interaction on typical structures built in Acapulco (Romo, 1989). Of

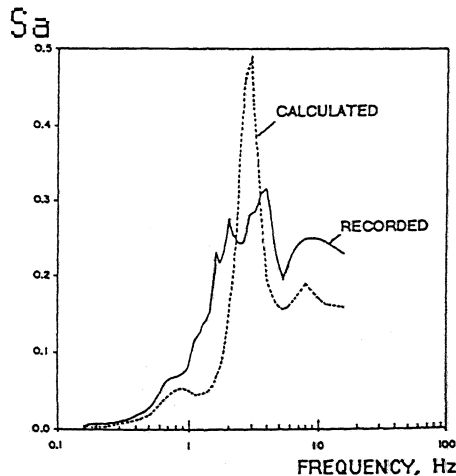


Figure 7. Response spectrum at the Casa de la Cultura Station, April 25, 1989. S_a is the spectral ordinate in g's.

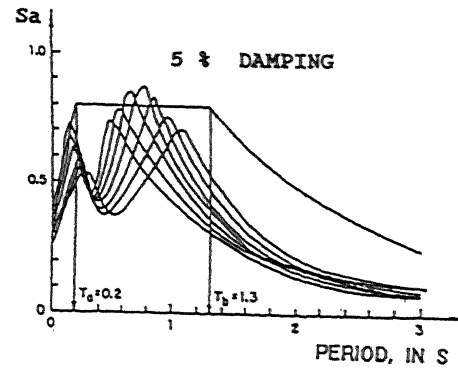


Figure 8. Calculated response spectra including nonlinear soil properties in Zone II.

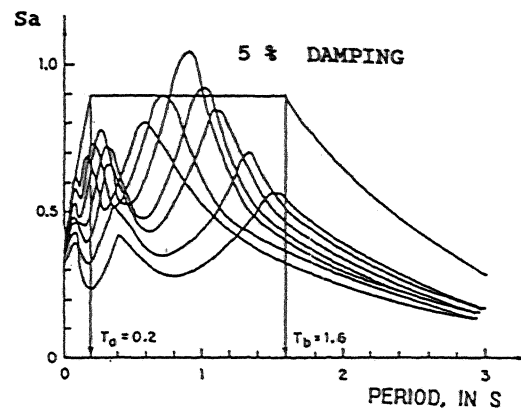


Figure 9. Calculated response spectra including nonlinear soil properties in Zone III.

course, given the general nature of the study, only some of the aspects of the problem were analysed in a restricted manner; in particular, the effect of foundation embedment depth. The program PLUSH, used in the other parts of the study was also employed here (Romo et al, 1980).

A stratigraphy corresponding to Zone III and having a dominant period equal to 1 s (i. e. the limiting value for soil deposits in Acapulco), was taken to perform the analysis; its characteristics are shown in Fig 10. Hypothetical structures having average dynamic properties typical of many high rise structures in the port were studied. The design spectra for firm ground was used as input excitation at the base of the deposit.

In the first set of cases in the analysis, structures with a fundamental period of 1 s —equal to the

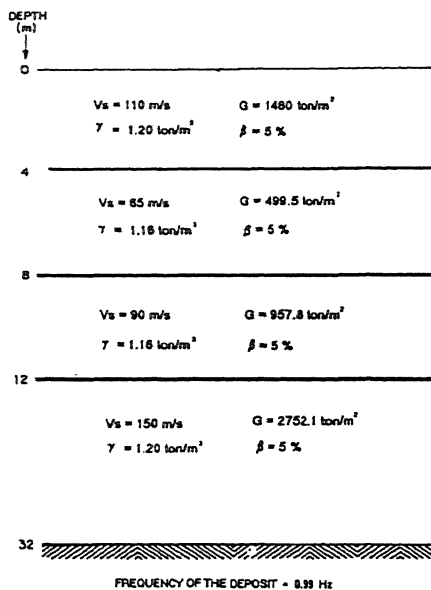


Figure 10. Soil profile for the soil-structure interaction analyses.

deposit's dominant period—and varying depths of embedment were studied. Typical results are given in Fig 11. The abscissas in this graph are horizontal distances from the centre of the building normalized by the foundation width; the ordinates, A_a in the figure, are the quotients of maximum surficial (ground level) accelerations considering the presence of the building divided by free field accelerations at the same points. This quotient is consequently a measure of the amount of interaction along the building's base. For surficial foundations, $D = 0.0$ in Fig 11, interaction effects are negligible and grow progressively with increasing embedment depth; at $D = 12.0$ m, for instance, interaction reduces free field accelerations in about 13 %. Horizontally, the effect of interaction also increases with D . When the structure is more flexible interaction effects are more pronounced, as shown in Fig 12 for a building having a fundamental period of 2.0 s; in this case, free field accelerations reduce 16 % for $D = 12$ m. These reductions are moderate but may warrant the convenience for performing soil-structure interaction analyses in many of the larger structures planned to be built in Acapulco.

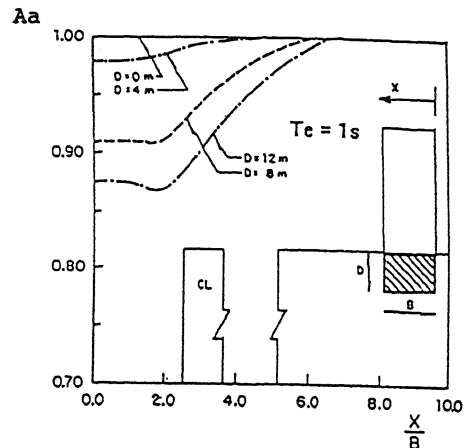


Figure 11. Results of soil-structure analysis, $T_c =$ structural period = 1s, A_a is defined in the text.

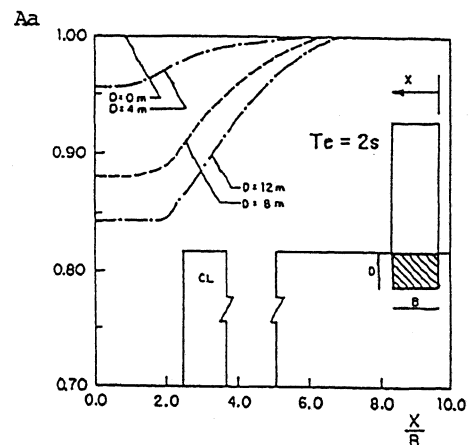


Figure 12. Results of soil-structure analysis, $T_c =$ structural period = 2s, A_a is defined in the text.

7. CONCLUSIONS

Data available from conventional soil mechanics' studies allowed for the definition of microzones in Acapulco on the basis of broad geotechnical characteristics. Average dynamic properties for soil deposits in each of these zones were obtained from ambient vibration measurements and from the depths of deformable strata. A one dimensional wave propagation model was calibrated using accelerograms from an earthquake recorded within the bay zone. The model yields fairly accurate values of any site's dominant period but in the higher

frequencies it underestimates spectral ordinates.

Material non linearities in the soils' stress-strain relationships were shown to have an important effect on local site response. Non linear effects are especially significant when using the postulated design spectrum for firm ground as the input excitation in the response of typical soil deposits in Acapulco. Envelopes calculated introducing explicitly non linear soil characteristics with a linear equivalent model were used to derive design spectra at each of the microzones.

The design spectra obtained from these studies pose very high demands on most structures, even allowing for reductions due to ductility or other structural non linearities. A parametric study into the effects of soil-structure interaction on typical buildings having different embedment depths shows that base floor spectra can be reduced in as much as 13 to 16 %, depending on the structure's fundamental period. These reductions may warrant the necessity to perform soil-structure interaction analyses in many high rise buildings in Acapulco.

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