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ESTIMATION OF DINAMIC CHARACTERISTICS OF SOILS FOR CODE PURPOSES

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ABSTRACT

Linear-elastic design, response spectras for a city are obtained through statistical estimation of soil periods and amplification factors obtained from ambient - noise vibrations, and from comparissons with real earthquake records.

KEYWORDS

Fourier spectra; cross-spectral density transfer function; soil periods; amplification factors; response spectras.

INTRODUCTION

The city of Guayaquil is located on one of the shores of the Gulf of Guayaquil, in the North west of South America. As it is well known, the border between the Nazca and the South American plates goes along the South American coast and passes by at about 25 Km from the Ecuadorian coast. Several earthquakes coming from this border have affected the city, being one of the most important the May 13, 1942 (Ruffili, 1942), 8.2 Richter magnitude event located at about 250 Km towards the NW of Guayaquil. This earthquake that damaged several buildings and induced the collapse of three five story reinforced concrete (RC) buildings, when there were only five five to seven story buildings and 63 less than five stories high RC buildings, clearly demonstrated the influence of the dynamic characteristics of the soft clay on the dynamic characteristics of the motion and therefore on the structural response.

The epicenter of the August 18, 1980 5.6 Richter Magnitude event was located on a secondary fault, 65 Km towards the SE of Guayaquil (Lara, 1988) although it did not induce a large amount of damage, it showed the same pattern of damage in the downtown area compared to that observed during of 1942 event, including damage to old houses, cracking of brick walls and some damage to RC structural elements in other areas where the depth of the clay is similar or larger than that of downtown. In 1942 the city was only 24 Km^2 with 200.000 inhabitants, nowadays it is 150 Km^2 with 2 million inhabitants, consequently, the damage potential from severe earthquakes like that of 1942 is now quite greater than in the past.

GEOTECHNICAL CHARACTERISTICS OF THE CITY

Figures 1 and 2 show the soil profiles of several areas of the city, and figure 3 indicates the location of the borings.

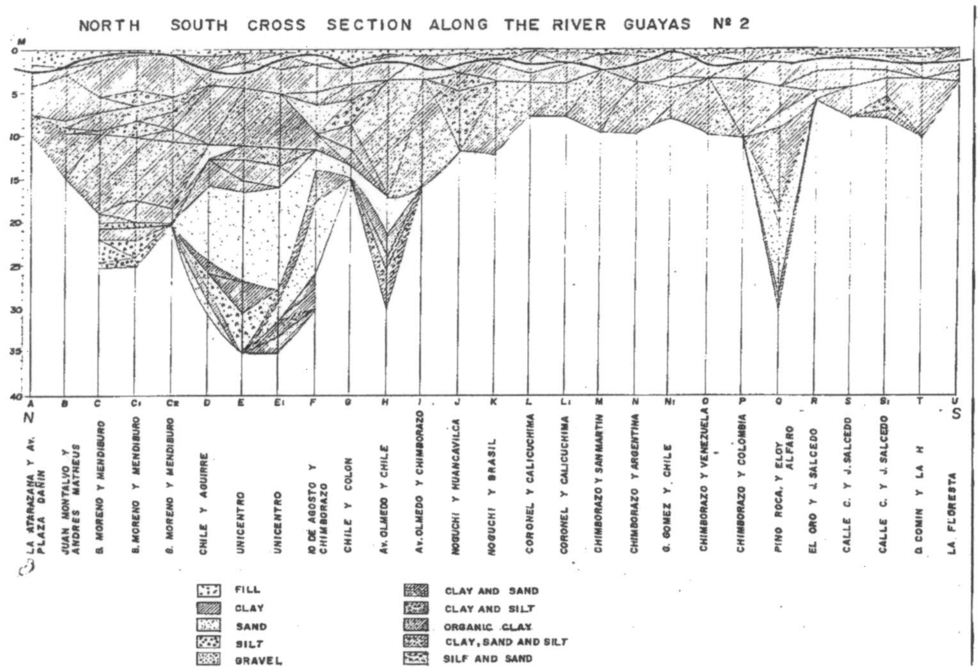

FIG. 1. SOIL PROFILE DIRECTION NORTH - SOUTH

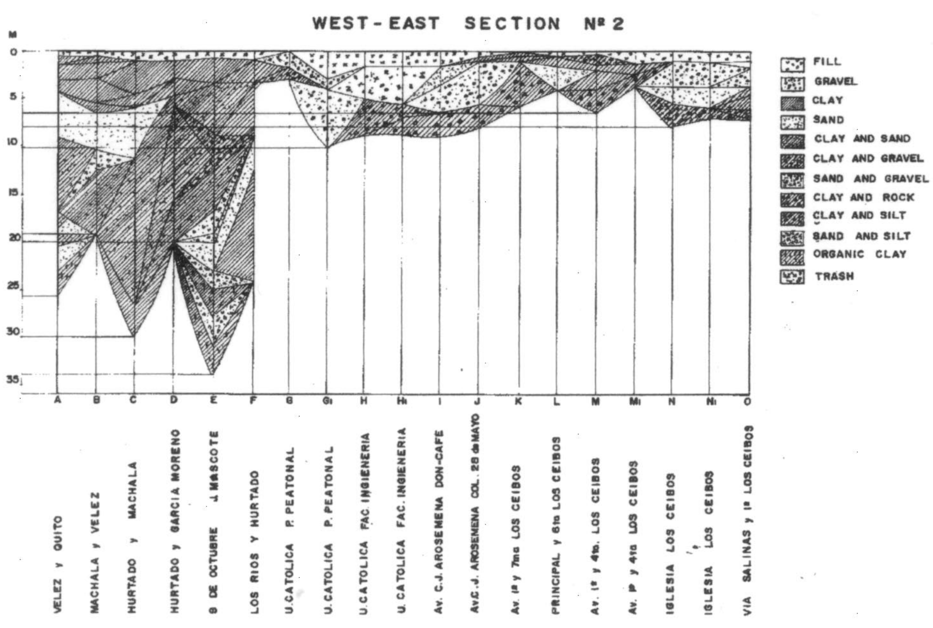

FIG. 2 SOIL PROFILE DIRECTION WEST - EAST

Clearly, most of the area is on a very soft clay with different depths that vary from 15 to 50 m. after which a sand strata which increases in density with respect to depth, appears. There are only few places where the rock outcrops on the surface as it is shown in figure 3 in a reduced area towards the NW part of Guayaquil.

Due to the presence of a very high water table as well as the mechanical characteristics of the clay, liquid limits between 85 and 130% are found in most of the borings. The shear capacity of the soft clay is in the order of 0.01 to 0.02 N/mm^2 whereas that of the rock is in the order of 0.2 to 0.3 N/mm^2.

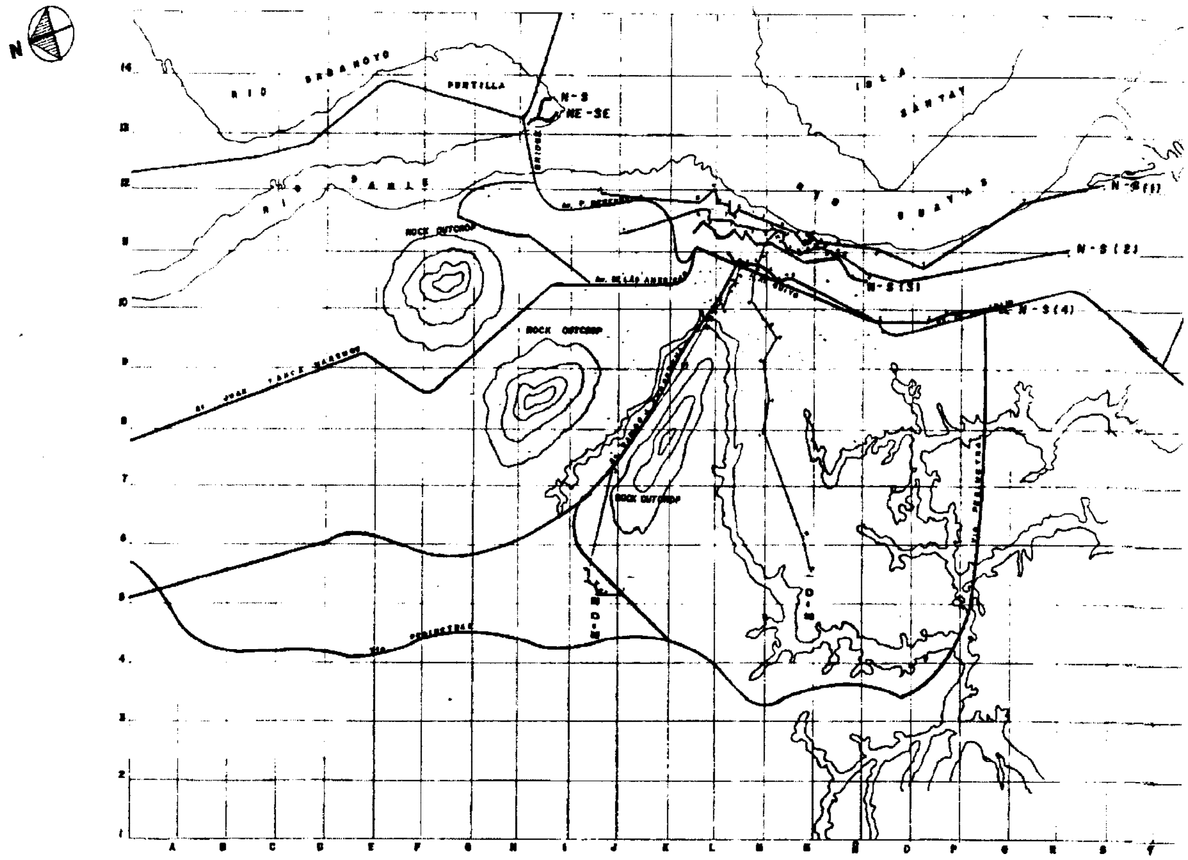

FIG. 3 LOCATION OF BORINGS ON GUAYAQUIL CITY

AMBIENT-NOISE MEASUREMENTS

Although it is very well known that ambient vibrations induce very small deformations in the soil compared to those during earthquakes, the estimation of the natural periods of soil deposits is related to the linear elastic behavior of the soil, therefore the ambient-noise measurements procedure can be considered appropriate as to evaluate dynamic site response characteristics.

Using the isoseismals of the 1980 tremor, 600 sites, most of them over the soft clay above described and some over the rock that outcrops in a very reduced area of the city, were instrumented with two horizontal and one vertical five seconds seismometers, which records were saved in a digital portable recording equipment. For each site, 2 one minute records were taken with a sampling rate of 100 lectures per second. The reference bedrock site is located at the Northwest just besides an accelerograph station. The records were taken continuously since 1992 to 1995.

ANALYSIS PROCEDURE

Due to the severe random fluctuations induced by undesirable perturbations called noise on ambient vibrations, the Fourier analysis procedure cannot be applied directly. Therefore it is necessary to consider a statistical approach in order to obtain average values of the measurements performed for each site.

STATISTICAL PARAMETERS

The amplitude of the noise varies randomly. Let n(t) be the noise function and let the average of the noise be equal to zero:

$$\lim_{T\to\infty} \frac{1}{T}\int_{-\frac{T}{2}}^{\frac{T}{2}} n(t)dt = 0 = E[n] \tag{1}$$

If f(t) is the recorded signal. s(t) the true part and n(t) the noise part of f(t) then, it can be demonstrated that:

$$\mathbf{Rsn(\tau)= 0} \quad \textbf{for all values of } \tau. \tag{2}$$

Where Rsn (τ) is the average correlation function between s(t) and n(t), meaning that the true and noise signals are not correlated. On the other hand, if g(t) is the input signal, f(t) is the output signal, s(t) the true part and n(t) the noise part of the output signal, it can be demonstrated that:

$$\mathbf{Rfg\ (\tau) = Rsg\ (\tau)} \tag{3}$$

since

$$\mathbf{Rng\ (\tau) = 0} \tag{4}$$

This means that

$$\mathbf{f(\tau) = s(\tau)} \tag{5}$$

Therefore

$$\mathbf{Rff\ (\tau) = Rss\ (\tau)}, \textbf{ as long as } \mathbf{Rfg \neq 0} \tag{6}$$

Finally, the cross-power spectral density is the Fourier transform of the cross-correlation of a function and becomes the best statistical estimation to determine frequency characteristics from ambient vibrations since the cross-correlation is the mean or expected value of a function.

Considering the recording at a rock site as the input signal or reference signal and the recording at any other site as the output, the transfer function between both cross-power spectral densities will be used to estimate site dynamic characteristics. This can be expressed as

$$\mathbf{|H\ (\varpi)|^2 = Pfg(\varpi)/Pg(\varpi)} \tag{7}$$

Where **H(ϖ)** is the transfer function or the spectral density of a system
Pfg(ϖ) is the cross- spectral density and **Pg(ϖ)** is the spectral density of the input signal.

In this way soil periods as well as amplification of soil deposits with respect to the rock are obtained. It is important to mention that it is not possible to obtain an explicit expression of the noise or that of the response of a system to a noise function. However through the cross-power spectral densities and applying equation(7), it is possible to establish the relationship between the output and input functions when noise is present. It should be mentioned that in order to determine the linear relation between the input and the output, the ordinary coherence function between the two signals at frequency w=Wk has been determined.

$$\mathbf{|Cgf(Wk)|^2 = |Pgf(Wk)|^2 / Pg(Wk)\ Pf(Wk)} \tag{8}$$

$$\mathbf{0 \leq Cgf\ (Wk) \geq 1} \tag{9}$$

Where **Pgf** is the cross-spectral input-output signals.
If **Cgf** = **0**, the recorded output evaluated at the frequency under investigation is entirely due to noise.
If **Cgf** = 1, the output is noise free.

The coherence has been determined for each pair of input-output signals. For this particular study, if the coherence evaluated at the maximum amplitudes of the signals is weak, then the peak response is not due to a resonance of the soil deposits but to noise. On the contrary, if the coherence is strong, the peak is due to a resonant behavior of the soil deposits.

RESULTS

To obtain the statistical estimations each one minute record was divided into six segments of 1000 values each (L. Lefrancois and J. Y. Chagnon, 1995). Fourier transforms, coherence functions, transfer functions for power spectral densities and for cross-power spectral densities were obtained after averaging the segments for each longitudinal record and for each site, being the reference the rock site above indicated. Of the two measurements obtained for each site, the one with the weakest coherence was neglected. Coherence values with strong linearity over the 0 to 30 Hz. ratio were considered appropiated.

Transfer functions for power spectral densities showed very large amplification factors, between 1.2 and 187, and the average had a large variance. On the other hand, the cross-power spectral density procedure showed a strong linearity in the coherence between the 0 and 30 Hz. Amplification factors between 1.3 and 30 are obtained with this approach which are more realistic than those obtained with the power spectral procedure.

Figure 4 shows the cross-spectral transfer function between the soft clay and the rock sites for downtown area of the city and figure 5 shows the coherence function for the same area. Notice that the average coherence is 0.55 for the frequency under study (0.7 Hz), showing that the noise is moderate. Figure 6 shows the isoperiods obtained through the cross spectral densities and figure 7 the amplification factors.

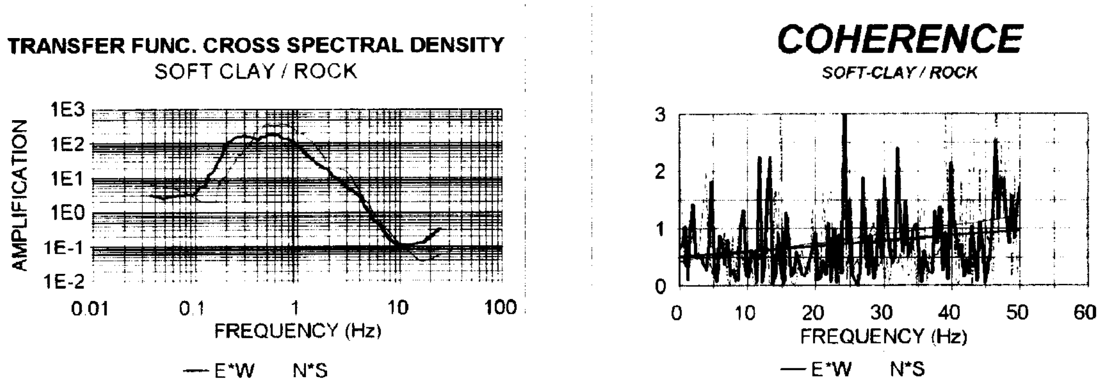

FIG. 4 AND 5 , RESULTS FROM AMBIENT - NOISE RECORDS

COMPARISSON OF RECORDS

Considering the accelerograph records obtained after moderate earthquakes which epicenters are located at more than 60 Km from Guayaquil, cross-spectral densities between soft clay and rock records were obtained. Fig. 8 shows the transfer function of the cross-spectral density of a downtown record with respect to the rock site. Clearly the maximum energy content is in the same range of that showed in figure 4 for ambient-noise record. Similar situations are observed in other transfer functions of cross-spectral densities related to accelerograph records obtained in sites were ambient vibration record have been obtained.

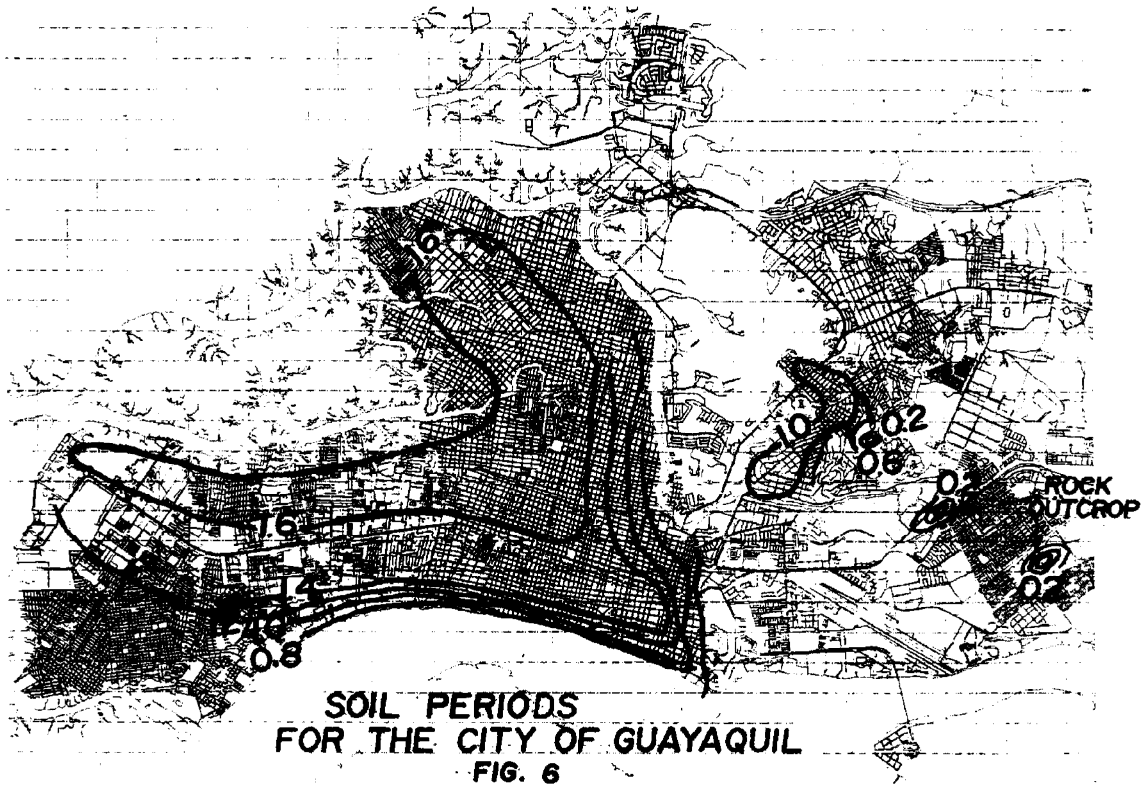

FIG. 6 ISOPERIODS OF GUAYAQUIL CITY

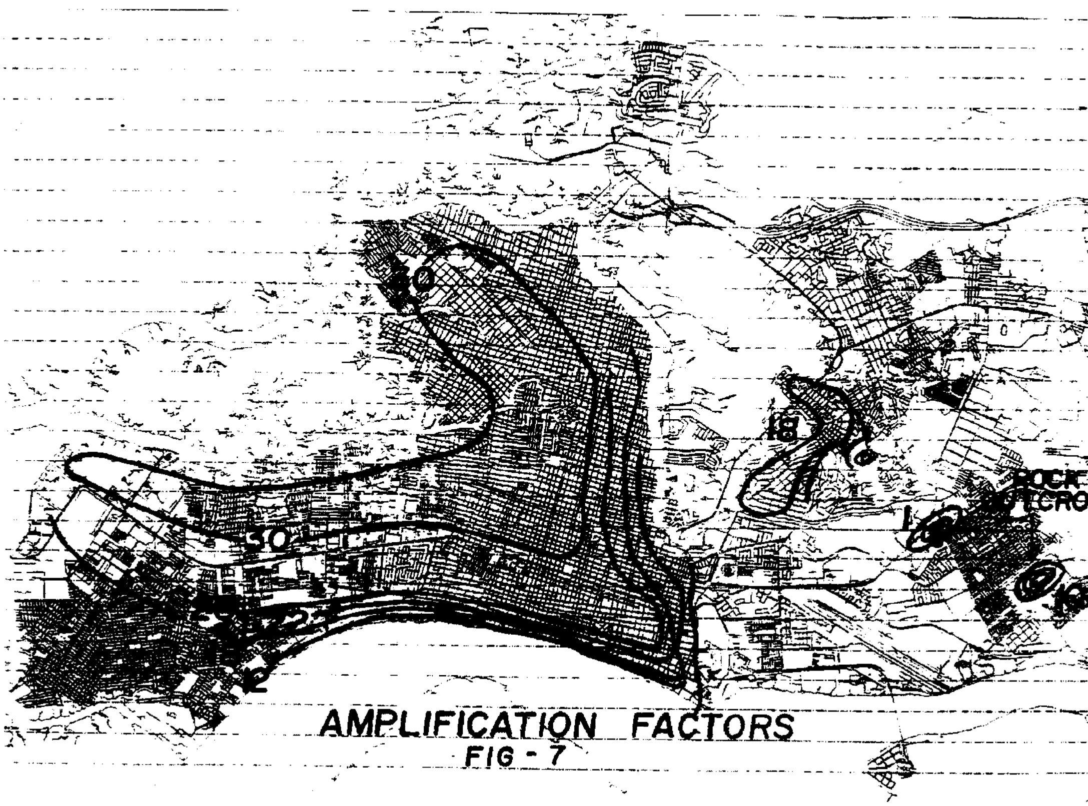

FIG. 7 AMPLIFICATION FACTOR OF GUAYAQUIL CITY.

LINEAR-ELASTIC RESPONSE SPECTRA

Using the moderate earthquake records above mentioned, normalized linear-elastic response spectras were obtained. Fig. 9 shows the one for downtown. Considering the isoperiods lines, amplification factors obtained for the city and expected soil acceleration, and linear elastic response spectras from moderate earthquake records, normalized to 0.06g, (Figs. 10 to 12), the following code design response spectras were obtained. (Figs. 13 to 15).

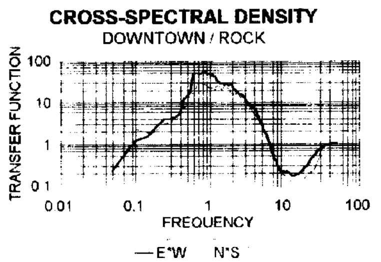

FIG. 8 TRANSFER FUNCTION (ACCELEROGRAPH RECORDS)

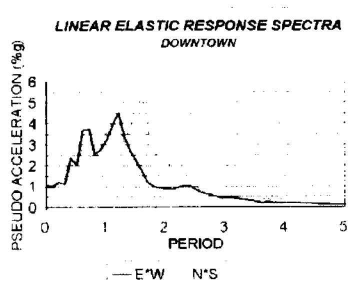

FIG. 9 DOWNTOWN NORMALIZED RESPONSE SPECTRA

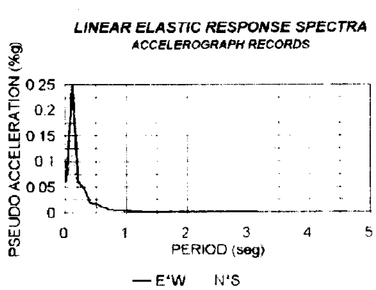

FIG. 10

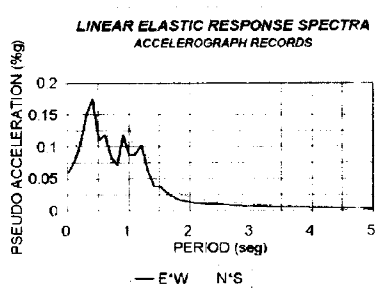

FIG. 11

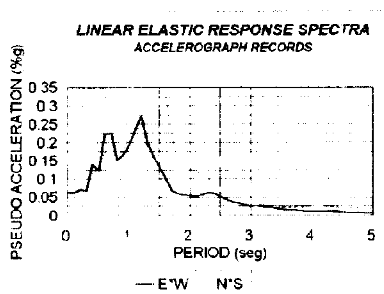

FIG. 12

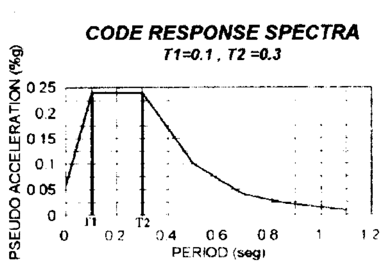

FIG. 13
ROCK SITES

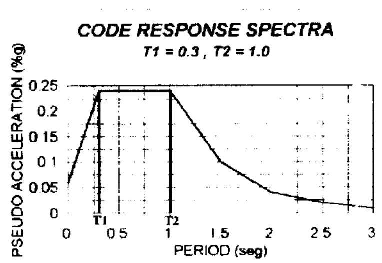

FIG. 14
INTERMEDIATE SITES

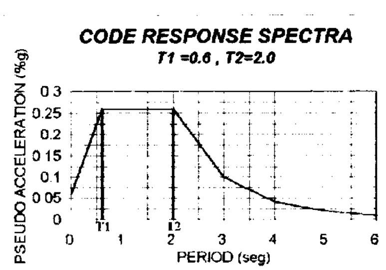

FIG. 15
SOFT-CLAY SITES

After T2 : Psa = (T/T2)^2/3

CONCLUSIONS

The cross-spectral density procedure appears to be the best statistical parameter in order to obtain good estimates of soil periods and soil amplification factors.

Ambient-noise vibration test provide very good results for estimation of soil dynamic characteristics when compared to moderate earthquake records.

Finally, the soil periods obtained through ambient vibration tests allow the establishment of the boundaries of linear elastic design response spectras for cities subjected to earthquakes and with different soil dynamic characteristics

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