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RELATIVE AMPLIFICATION AND DOMINANT PERIODS MAP FOR SEISMIC MOTION IN COLIMA CITY, MEXICO

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ABSTRACT

In order to evaluate dominant periods for the Colima urban area, microtremors were observed in 57 places, using sensors with natural periods of 1 and 5 seconds. To determine relative amplification factors, earthquakes with magnitudes between 3.2 and 4.5 were recorded at 8 sites, 7 in the urban area, mainly on volcanic breccia and alluvial soils, and one in a limestone outcrop used as a reference site.

On the other hand, to estimate the thickness and differences in dynamic behavior of the materials in Colima valley with respect to hard sites at opposite edges, microtremors were observed along a 24 km line crossing the valley.

P and S velocity determination using a logging system permitted to define a shallow two-layer structure for the Colima urban area which can be useful to estimate soil response during strong motion.

KEYWORDS

Microzonation, microtremors, relative amplification, spectral ratios, P-S velocity logging

GEOLOGY AND SEISMICITY

Colima and Jalisco coastal area is considered one of the main seismogenic zones in México. Although its seismicity level is rather low in comparison with the Guerrero area, great magnitude earthquakes have been observed during this century (Singh *et al.*,1985). The greatest earthquake (M 8.2) occurred in México during this century was observed in june 1932 at the coast of Jalisco. Recently, in october 9, 1995 an earthquake with magnitude 7.9 occurred in the Jalisco-Colima coast. This has clearly shown the importance of the assessment of the dynamic behavior of soils for big cities in the region.

Colima city is located in the Colima graben which, with Zacoalco and Chapala grabens, could represent an incipient triple point (Lurh and Carmichael, 1981). Inside the Colima graben an intense volcanic activity is characteristic. The most representative feature is the Colima volcano, located in the northern edge of the city and considered the most active in México. Then, seismic risk for Colima is related with seismic events with inland and coastal sources.

Colima city has been built on four types of deposits: conglomerates, mainly on the eastern side of the city; to the west side, sandy conglomerates are predominant, showing weathering on shallow parts although cohesion increases with depth. In the southern portion of the city alluvial deposits are widely distributed. The northeastern part of the urban area, where more than 50 % of the population is concentrated, is on andesitic breccia. Its important to point that there is a strong tendency to let the city grow towards north, on this kind of materials (Fig. 1).

It has been estimated by geophysical and geological studies (López and Gutiérrez, 1977) that volcanic avalanche deposits in the valley could reach a thickness of 700 m, overlaying cretacic limestone.

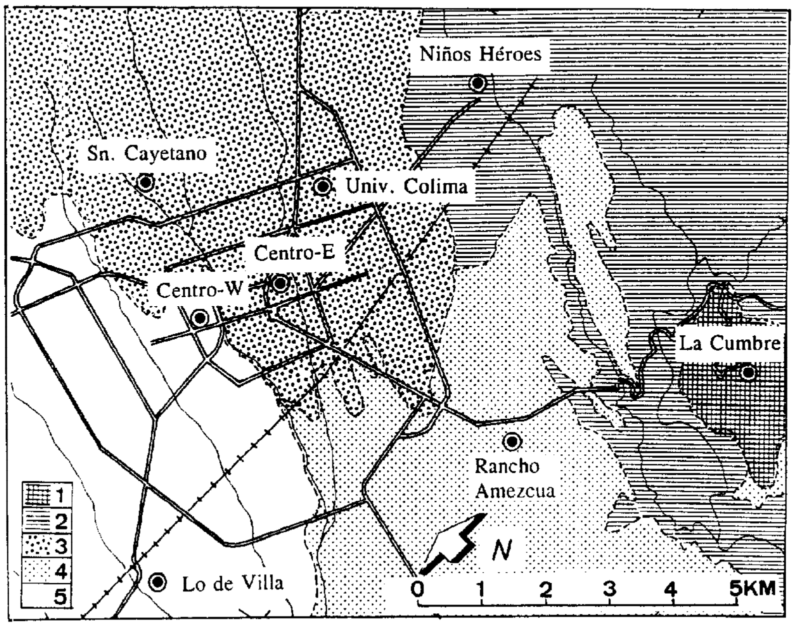

Fig. 1. Surface deposits at Colima city and sites for seismograph installation. The numbers correspond to materials as follows: 1) Limestone, 2) conglomerate,3) andesitic breccia, 4) alluvium and 5) sandy conglomerate.

RELATIVE AMPLIFICATION ESTIMATES

Instrumentation and recorded earthquakes

During july and august 1994, digital EDA seismographs were used to record earthquakes for the evaluation of amplification factors. The natural period of the three-component Lennatz sensors is 1 second and the information was stored in solid state memory. To deploy these instruments 8 sites were chosen taking into account the different kinds of soil described above, as well as the growing trend of the city (Fig. 1). The station used as a basis to compare the motions recorded in the urban area was La Cumbre, located on a limestone outcrop at the southeast edge of the city. Geologists at Colima claim that limestone is the main bedrock in the valley, reaching depths of about 700 m (Navarro and Cortés, Univ of Colima; personal communication).

There is a previous analysis of relative amplification made by Lermo *et al.* in 1991, in which a different reference site was chosen on volcanic deposits; results are presented only for four sites inside the city using one earthquake with magnitude 3.5. However, it was considered important to verify and complement those results using a reference site like La Cumbre. With the array described it was possible to record, simultaneously at different sites in the city and La Cumbre, ten events with magnitudes Mc

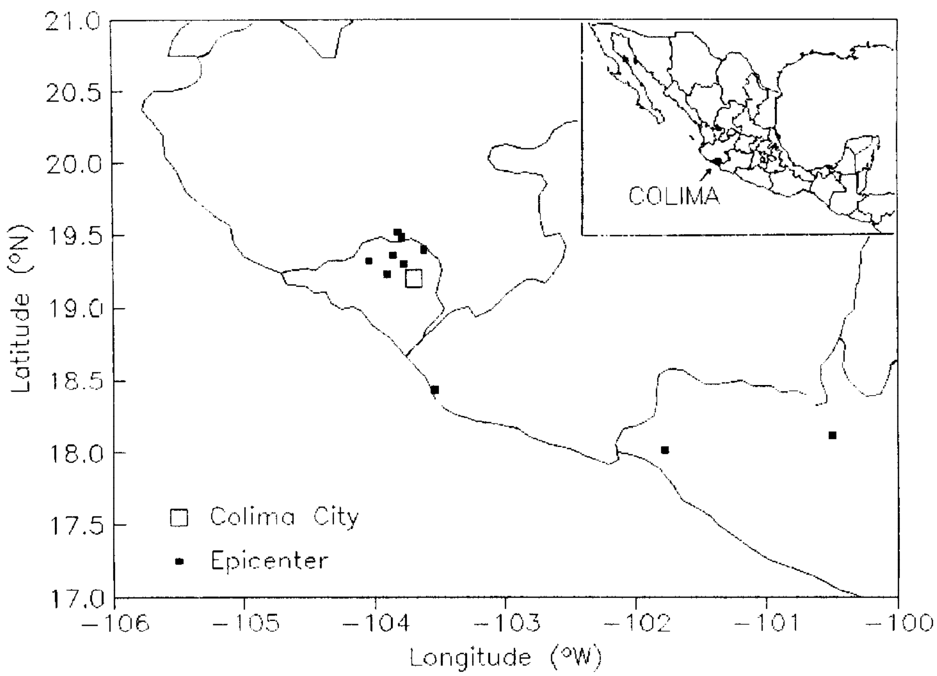

Fig. 2. Epicenters of earthquakes recorded for relative amplification estimates

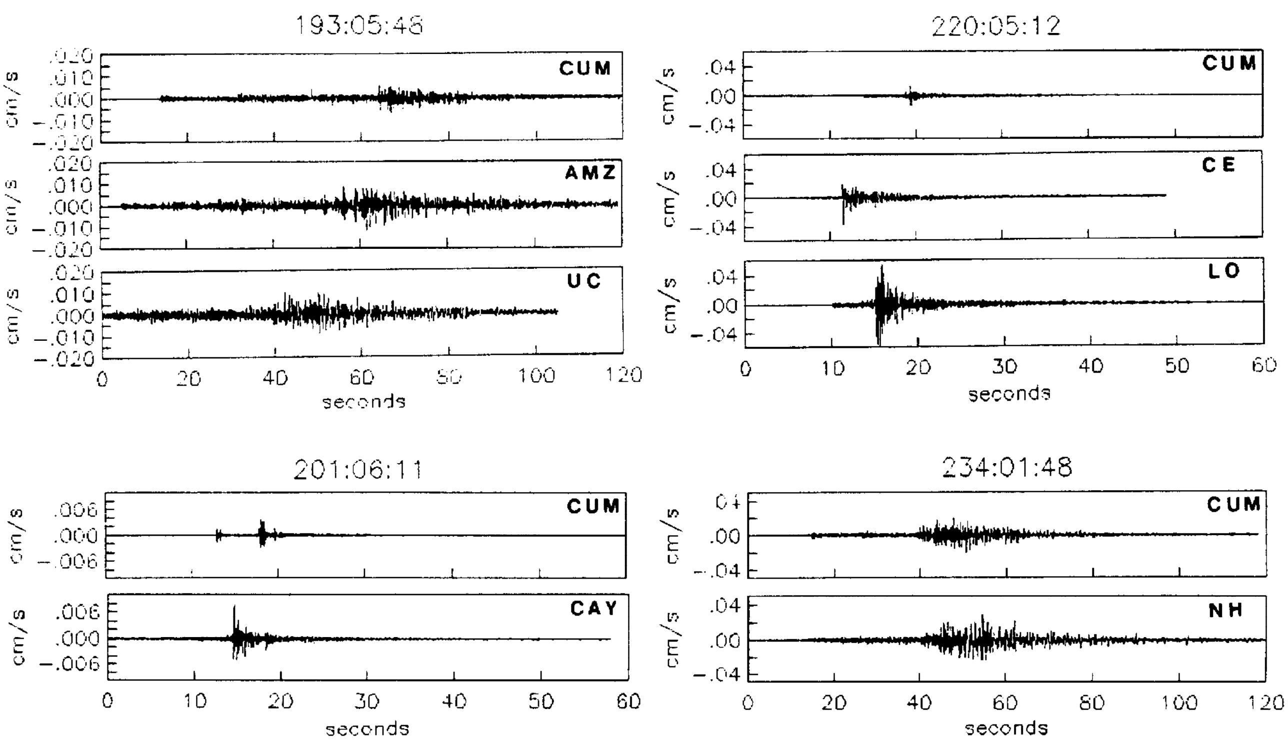

Fig. 3. North-South components of main events used for relative amplification estimates. Reference station signal (CUM) is at the top in every case. Six of the seven instrumented sites are represented (stations Centro-W (CW) and Centro-E (CE) showed similar behavior).

between 3.2 and 4.5, with depths between 11 and 62 km. The epicenters and time series are shown in Figs. 2 and 3, respectively. Most of the events were concentrated close to Colima city and with depths down to 25 km. For the farthest epicenter, located 370 km SE from the city, a depth of 62 km was calculated.

Spectral ratios

To estimate the relative amplification factors, the spectral quotient technique was applied. For all the events recorded simultaneously in urban and hard sites, amplitude Fourier spectra were computed for S and S-coda phases. In Fig. 4 the S-wave spectra for both urban and reference sites are presented together with the corresponding spectral quotients for north-south and east-west components, for the events in Fig. 3. At four of the seven instrumented sites 3 to 6 events were recorded, those places are: Rancho Amezcua (AMZ), University of Colima (UC), Centro-Este zone (CE) and San Cayetano (CAY). The first of them located on alluvium and the rest of them on andesitic breccia. In other stations only one earthquake was recorded simultaneously with the base station. In general, amplification factors do not exceed 6. The shape of both S-wave and S-coda waves spectral ratios are quite similar, although the amplification factors are greater for S-coda in most of the cases with values up to 9.

It is worth to mention that although seismic motion amplification can be recognized from spectral ratios it is not as significant as in other areas where amplification factors of 8 to 56 have been reported for soft deposits (Singh *et al.*, 1988; Gutiérrez and Singh, 1992). Furthermore, an outstanding prominence clearly indicating a predominant frequency is not observed in most of the ratios, particularly for stations on andesitic breccia. This suggests that: 1) deposits throughout the valley, particularly those due to volcanic avalanche, can be considered relatively hard and that corresponding stratigraphic boundaries are poorly

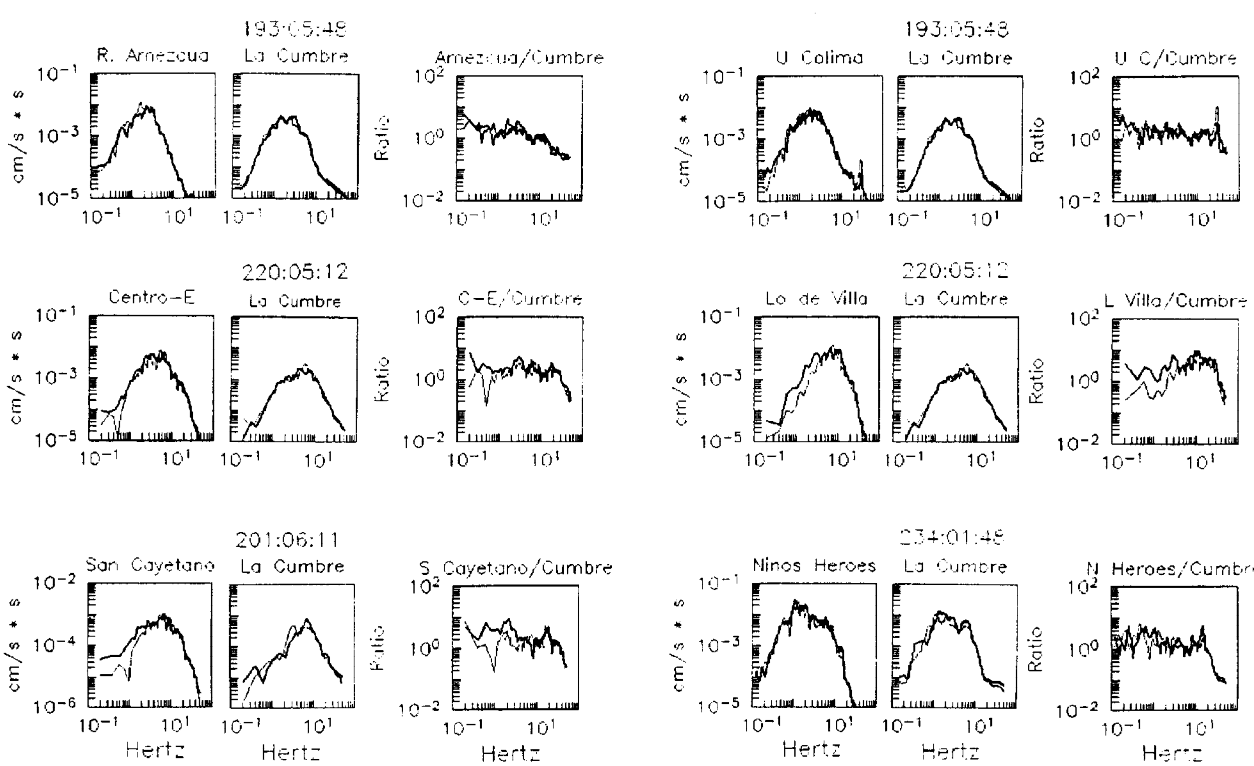

Fig. 4. Fourier amplitude spectra and spectral ratios for S phases of events in Fig. 3. Thick and thin lines are for NS and EW components, respectively.

defined; and 2) at the alluvium and conglomerate sites (e.g. Amezcua and Lo de Villa) the thickness of soft surface layers is relatively small.

ISOPERIODS MAP FROM MICROTREMOR ANALYSIS

The spectral analysis of microtremors has been widely applied in Japan and some other countries to evaluate the predominant periods of the ground. A few years ago it was applied in México City for microzonation, obtaining good results (Lermo *et al.*,1988)). It has been demonstrated by a large number of experiments that predominant periods for strong ground motion can be determined using microtremor analysis, specially where the acoustic impedance contrast between bedrock and soft deposits is high. In the case of Colima Valley, according to geological and geophysical reports, the contrast could not be so high. Taking this into account, microtremor analysis was performed for Colima city in order to estimate, as accurately as possible, the main differences of soil response during strong seismic motion.

The measurements were made along five lines oriented NW-SE crossing entirely the city. Two digital data acquisition systems were used, with three-component sensor sets of 1 and 5 seconds of natural period, respectively. Those lines were observed using both types of sensors, alternately (Fig. 5). Microtremor signals were measured during 90 seconds employing a sampling frequency of 50 Hz, always trying to

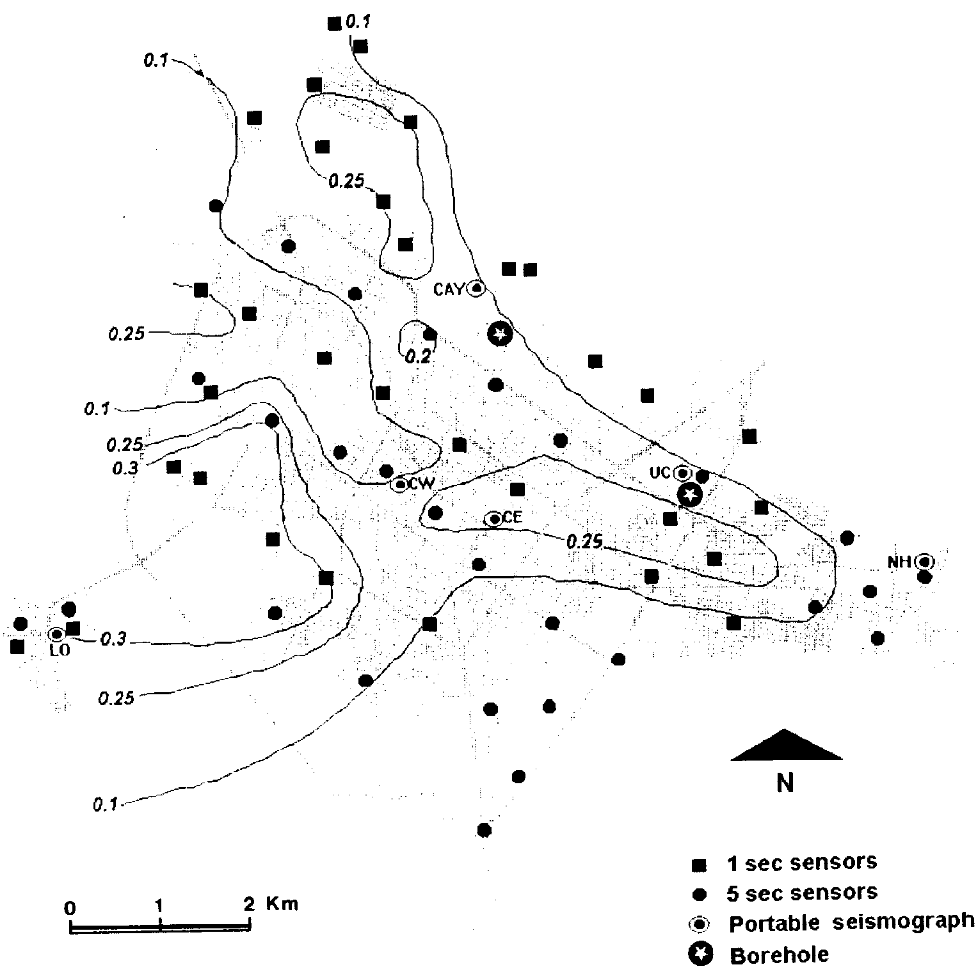

Fig. 5. Isoperiods map obtained from microtremor analysis.

avoid near-source effects, caused by human and vehicle transit nearby or industrial facilities. To compute Fourier amplitude spectra the entire recorded signal was usually taken, although sometimes, due to the presence of spurious signals, windows as short as 30 seconds were processed. The isoperiod lines on Fig. 5 do not strictly follow the distribution of surface materials as could have been expected from the thickness-period relation. However, it can be seen that a portion of the sandy conglomerate area, southwest of the city, clearly concentrates the longest periods in the region.

Stationarity test for dominant frequencies

In order to know if the predominant frequencies could present major changes with time in the urban area, measurements were made at Centro-Este (CE) station, every hour during a whole day. The results show that no significant changes can be seen, in this case for a spectral maximum at 3.5 Hz, specially between 6 and 21 hours, period in which human and industrial activities are at a high level.

MICROTREMORS ACROSS THE COLIMA VALLEY

Using 5 seconds sensors, microtremors were observed on a line between two hard sites: La Cumbre and Zacualpan, separated 24 km. The main purpose was to determine the spectral amplitudes and dominant frequencies for deposits across the valley (Fig. 6).

Considering that Colima volcano (Volcán de Fuego) is located in the north of the city and that avalanche deposits have a radial pattern, it is expected that thickness of deposits increases in the central part of the observation line. Sampling frequency was also 50 Hz and signal recording windows were of 180 sec. In most of the cases, a peak approximately at 0.3 Hz was observed, which can beinterpreted as microseisms mainly due to sea influence (Hatherton, 1960). However, not for all the spectra was possible to identify a peak at higher frequencies which could be associated with deposits through the valley.

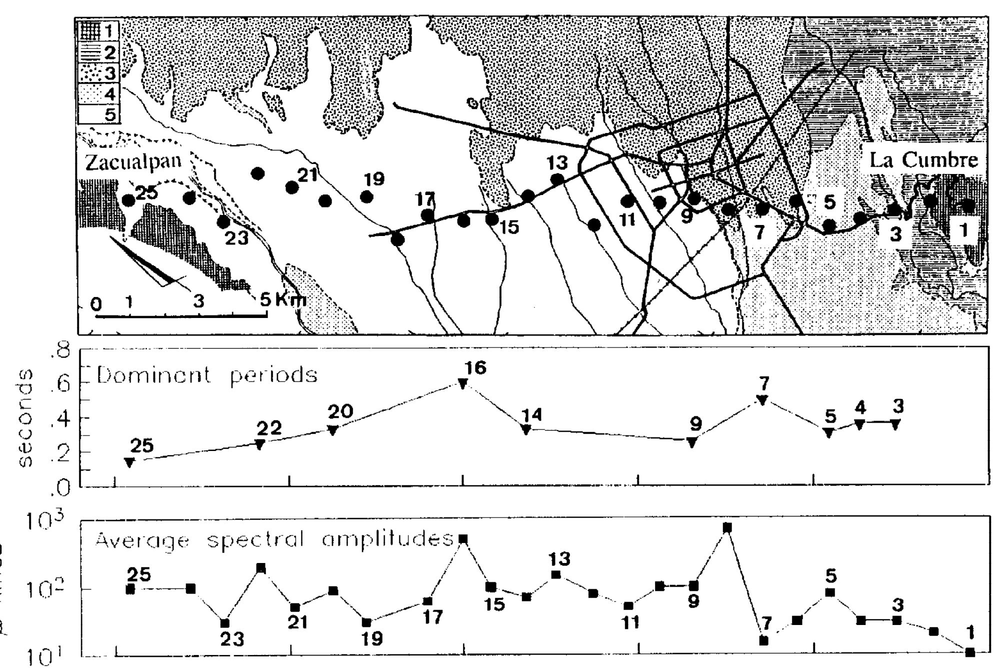

Fig. 6. Microtremor observation points (top) between two hard sites (1 Limestone, 2 conglomerate, 3 andesitic breccia, 4 alluvium and 5 sandy conglomerate). Dominant periods obtained only from best-defined peaks in amplitude spectra (middle) and average spectral amplitudes (bottom).

The following causes can be considered:

a) Deposits have a complex distribution with depth and low acoustic impedance contrasts,
b) the source energy is insufficient to excite completely the geological bodies of the valley,
c) the peaks which characterize ground behavior are masked by noise.

The amplitudes at the first 4 sites appear at very low level corresponding to firm ground. Point 5 has higher amplitude although its period is similar to the previous ones, suggesting that alluvium thickness is small. The points 6, 7 and 8 are located in a transition zone inside the city, because of which it can be expected that the signals are strongly influenced by local sources; the amplitude at those points changes drastically, while only for point 7 was possible to estimate the dominant period. Since the largest period was determined at point 16 with a significant increase of spectral amplitude, the sandy conglomerate deposits in this place could have its largest thickness. Amplitudes at points 24 and 25 close to Zacualpan, located on conglomerates with minor thickness on limestone, are rather reduced although greater than those at points 1 through 4. This effect can be produced by human activity within short distance.

P AND S WAVES VELOCITY DISTRIBUTION IN BOREHOLES

To analyze soil response during strong seismic motion it is important to know the thickness of major layers and its velocity distribution, specially for S waves. To obtain that information, refraction profiles or microtremor observation through instrumental arrays can be used. However, those velocities can be obtained more accurately with a PS logging system in boreholes located at places where the lithology is considered to be widely representative, although its high cost limits its repeated application in an area.

PS logging was performed at two boreholes with depths of 50 m and separated 2.5 km, made at University of Colima campus and Santa Bárbara up-town area, very close to CAY station (Fig. 5). The materials firstly found during drilling were tuffs until depths of 10 and 30 meters for Santa Bárbara and University areas, respectively. Andesitic breccia is supposed to reach, according to geologists, depths of about 700 meters.

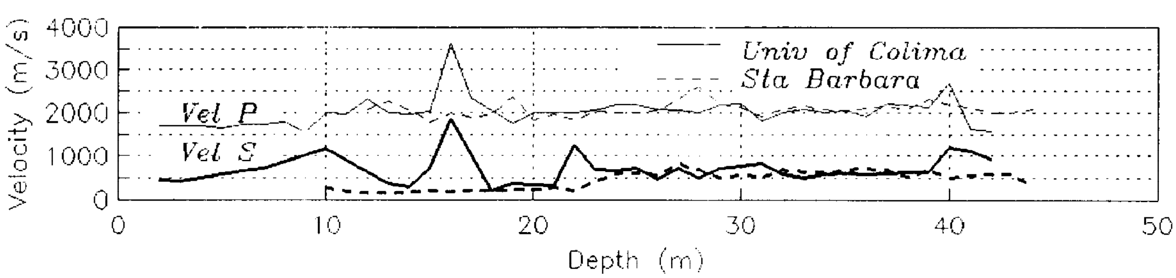

Fig. 7. Velocity distribution for P and S waves in boreholes at Colima city.

At both holes the velocity for S wave shows a clear change at 20 m, reaching values between 500 and 750 m/sec. This suggests that a boundary approximately at 20 m could be present in a large extent in this kind of deposits. With this results, a two-layer velocity model can be proposed with velocities of 220 m/sec and 600 m/sec for the upper and lower layers, respectively. Using the relation f_0=Vs/4H and values of f= 3.5 Hz (obtained from a stationarity test of 24 hours at CE) and Vs = 220 m/sec, H is almost 16 m. Although this thickness is smaller in comparison with that determined at boreholes, it is reasonable to expect that the thickness of this surface layer changes at different places.

On the other hand, since the velocity generally increases with depth and assuming that velocity for andesitic breccia could be 1000 m/sec at depths close to bedrock, the relation mentioned above gives a depth of 830 m, results quite similar to estimates reported in former studies (700 m).

CONCLUSIONS

Reasonable estimation of relative amplification was obtained for 4 sites at Colima city. Three more sites were analyzed using only one earthquake. Amplification factors do not exceed 6 for S phases. Since the maximum magnitude of the events used was 4.5 and the rigidity of predominant deposits is relatively high, amplification factors and dominant frequencies for greater magnitudes could present variations.

In most of the microtremor amplitude spectra a clearly defined peak showing the dominant period is hard to find. Isoperiods map was built following the general character of the information when big inconsistencies were found. Since Colima city is small and its activity level rather reduced, it is thought that the source energy is insufficient to excite completely a huge mass of volcanic deposits with high rigidity, obtaining sometimes poor definition of dominant frequencies.

Along La Cumbre-Zacualpan line only a rough estimation of thicknesses and dominant frequencies different from 0.3 Hz was obtained. The greatest thickness corresponds to the center of the valley close to a surface geological boundary.

Two boreholes were made on volcanic deposits where a high percent of the buildings is settled and still tend to increase on. A significant S velocity boundary was determined at about 20 meters allowing to propose a two-layer model for Colima city with thicknesses of 16 and 830 meters and velocities of 220 and 600-1000 m/sec, respectively.

Taking into account that the valley has been covered mainly with volcanic avalanche deposits producing a complex depositional pattern, and that microtremor analysis results are coherent with geological and geophysical explanations, the observation methods applied were useful to characterize the area.

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