CHAPTER 3

GEOTECHNICAL PROFILING AND EARTHQUAKE GROUND MOTION IN SEDIMENTARY BASINS

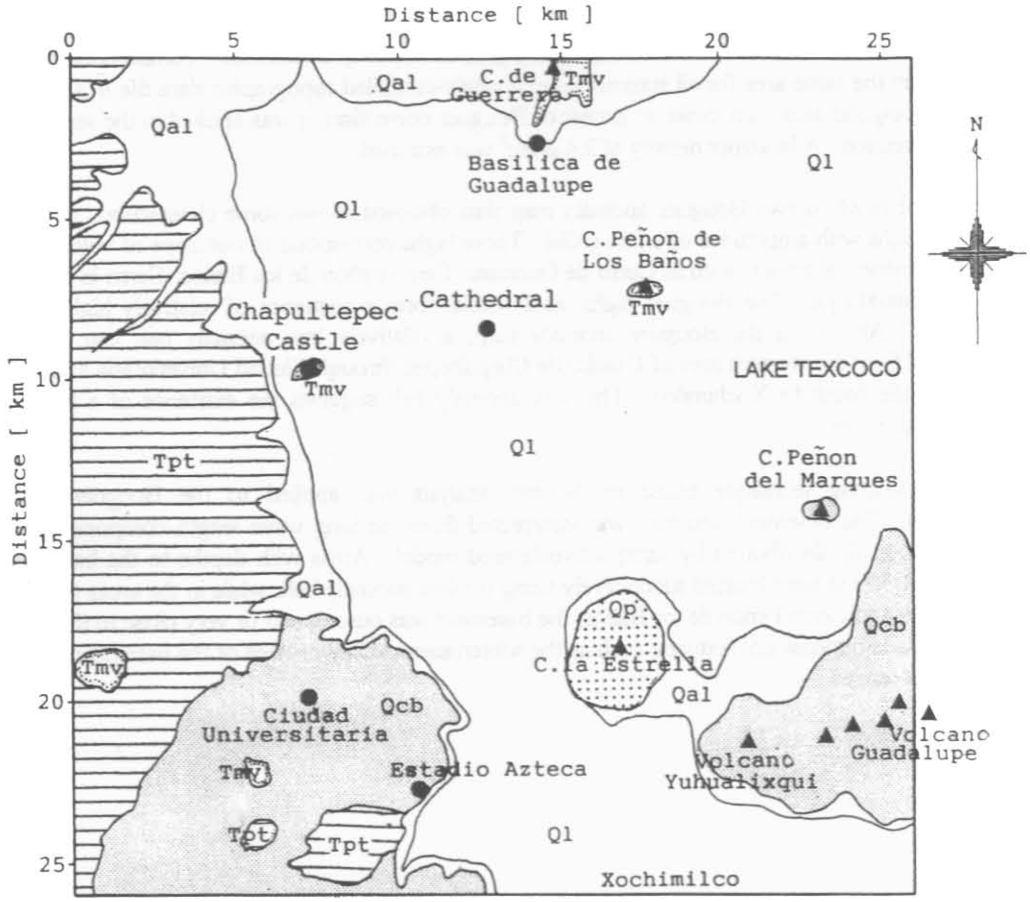
3.1. BASEMENT STRUCTURE OF THE CENTRAL PART OF THE MEXICO BASIN AS DERIVED FROM A GRAVITY SURVEY

Kyozo Nozaki, Yoshibumi Sato, Koji Hamada, Keiji Tonouchi and Yoshikazu Kitagawa

A land gravity survey in and around Mexico City was carried out from October through December, 1989. This survey area is located in the central part of the Mexico Basin. 566 gravity stations distributed over a 26 km x 26 km square area were newly established. Terrain correction was made within the same area for all stations using a newly-compiled topographic data file in a 104 km x 82 km rectangular area. To avoid an excess of Bouguer correction, it was applied in the same area of terrain correction. A Bouguer density of 2.4 g/cm^3 was assumed.

The newly-drawn Bouguer anomaly map thus obtained shows some conspicuous patterns of Bouguer highs with amplitudes of a few mGal. These highs correspond to outcrops of volcanic rocks or monogenetic volcanoes, such as Cerro de Guerrero, Cerro Peñon de los Baños, Cerro la Estrella or Volcán Yuhualixqui. The Bouguer highs, as a whole, form a sequence of relatively high Bouguer anomalies. Also from the Bouguer anomaly map, a relatively low anomaly belt can be clearly recognized from the western area of Castillo de Chapultepec through Ciudad Universitaria and Estadio Azteca in the south to Xochimilco. This low anomaly belt suggests the existence of a large-scale subterranean valley.

A filtering technique based on Fourier analysis was applied to the Bouguer anomaly distribution. The basement structure was interpreted from the long wave length components of the Bouguer anomaly distribution by using a two-layered model. Areas with depths to the basement of more than 1,500 m were located successively along the low anomaly belt, while in the areas near Cerro de Guerrero and Cerro Peñon de los Baños, the basement was outcropped or very close to the surface, revealing three-dimensional features, such as the subterranean valley or rises of the basement along the series of volcanoes.



▲: *Principal summit (monogenetic volano, etc.)* ●: *Principal landmark*
Ql: Lake deposit (Holocene) *Qal: Alluviem (Holocene)* *Qcb: Basaltic Lava (Holocene)*
Qp: Basaltic lava (Pleistocene) *Tpt: Tarango formation (Pliocene)* *Tmv: Volcanic rocks (Miocene)*

Fig. 3.1.1. Surface geological features shown in the same area of analysis (simplified from OYO Co. & Hirata Str. Eng. Co.)

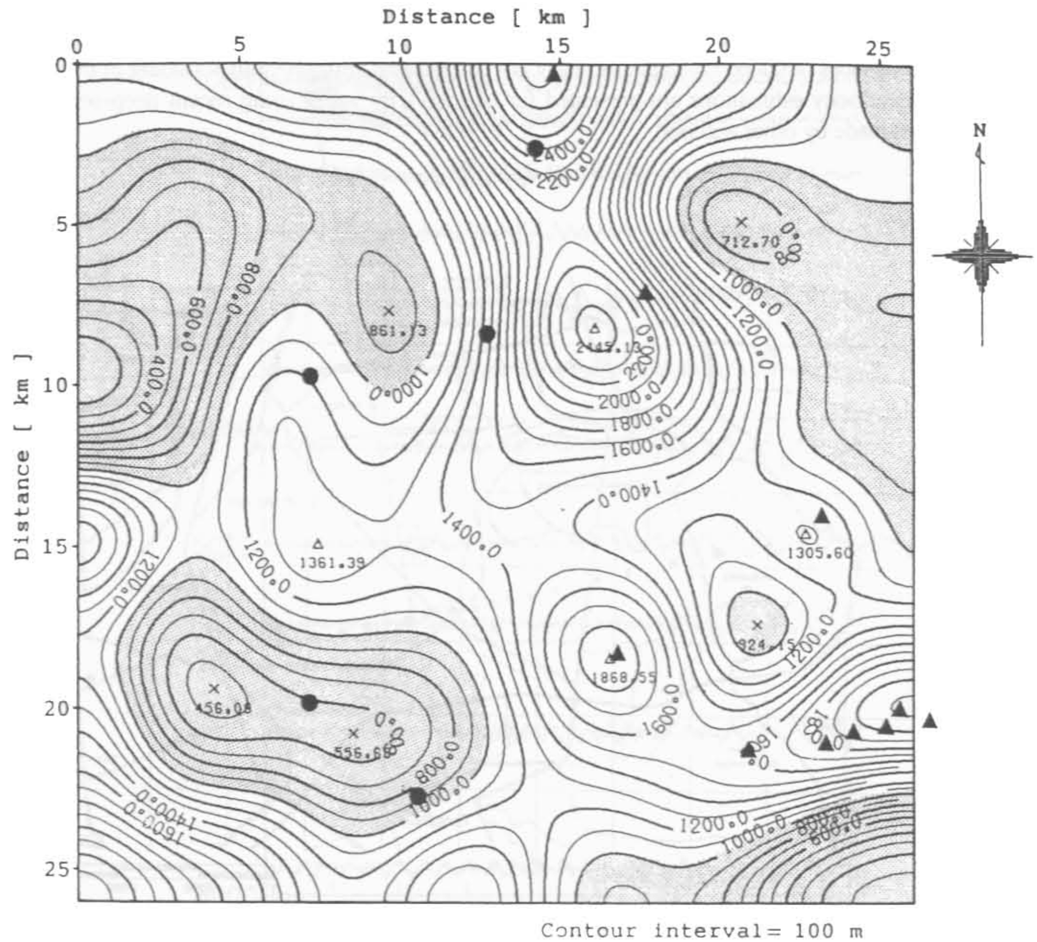
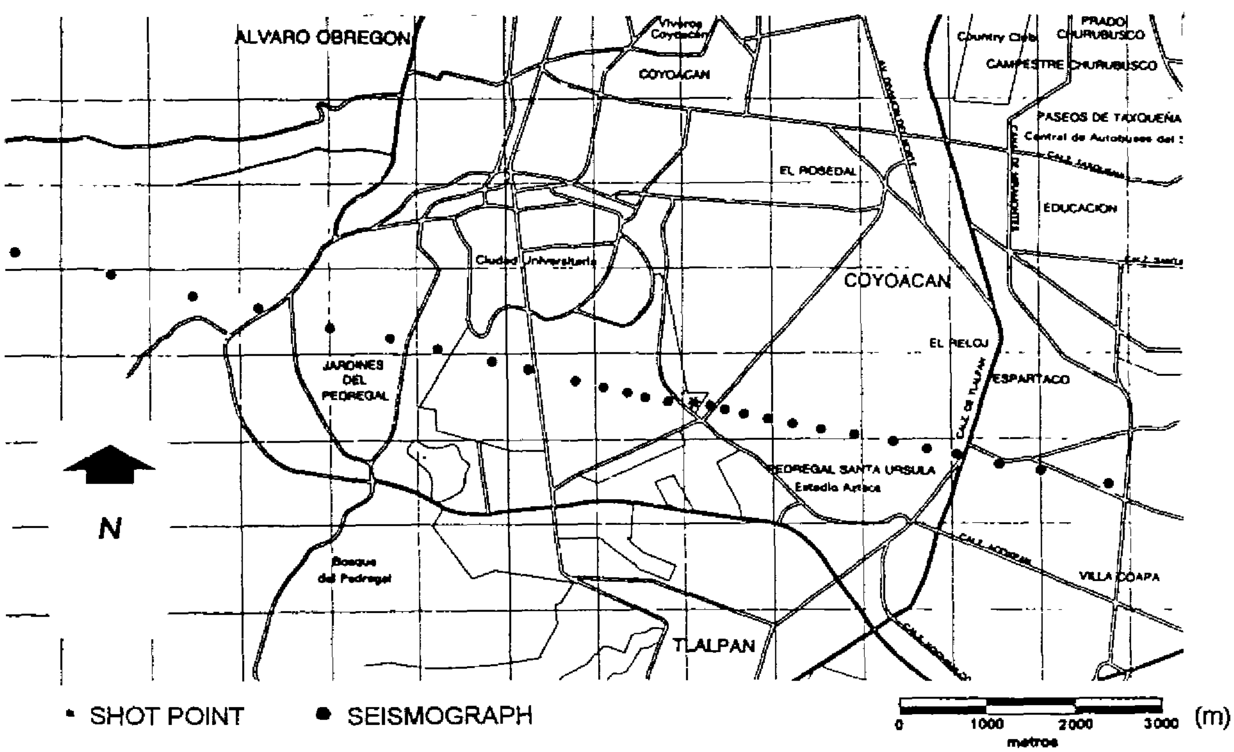


Fig. 3.1.2. Contour map of gravity basement represented in altitude. Areas lower than 1,000 m are indicated by hatching. Solid triangles and solid circles indicate principal summits and principal landmarks, respectively (see Fig. 3.1.1). Open triangles and crosses indicate the spots of local maximums and local minimums of the basement, respectively.

3.2. REFRACTION PROFILE IN THE SOUTH OF MEXICO CITY AND ITS CORRELATION WITH OTHER INFORMATION SOURCES

Carlos Gutiérrez M., Kazuyoshi Kudo, Emilio Nava A., Masumi Yanagisawa, Shri Krishna Singh, F. Javier Hernández M., Kojiro Irikura

A velocity model for P and S waves is presented for shallow layers in southwest Mexico City. These velocities were obtained through refraction profiles observed along an east-west line with length close to 13 km Both analog and digital instruments were used for the experiment. P and S velocities as well as the interfaces obtained through this study are comparable with previous founding in the area. Finally, P wave velocity estimations are presented for Mexico City valley using recent deep-sounding data and studies made by other authors.



3.2.1. Location of recording sites and energy source.

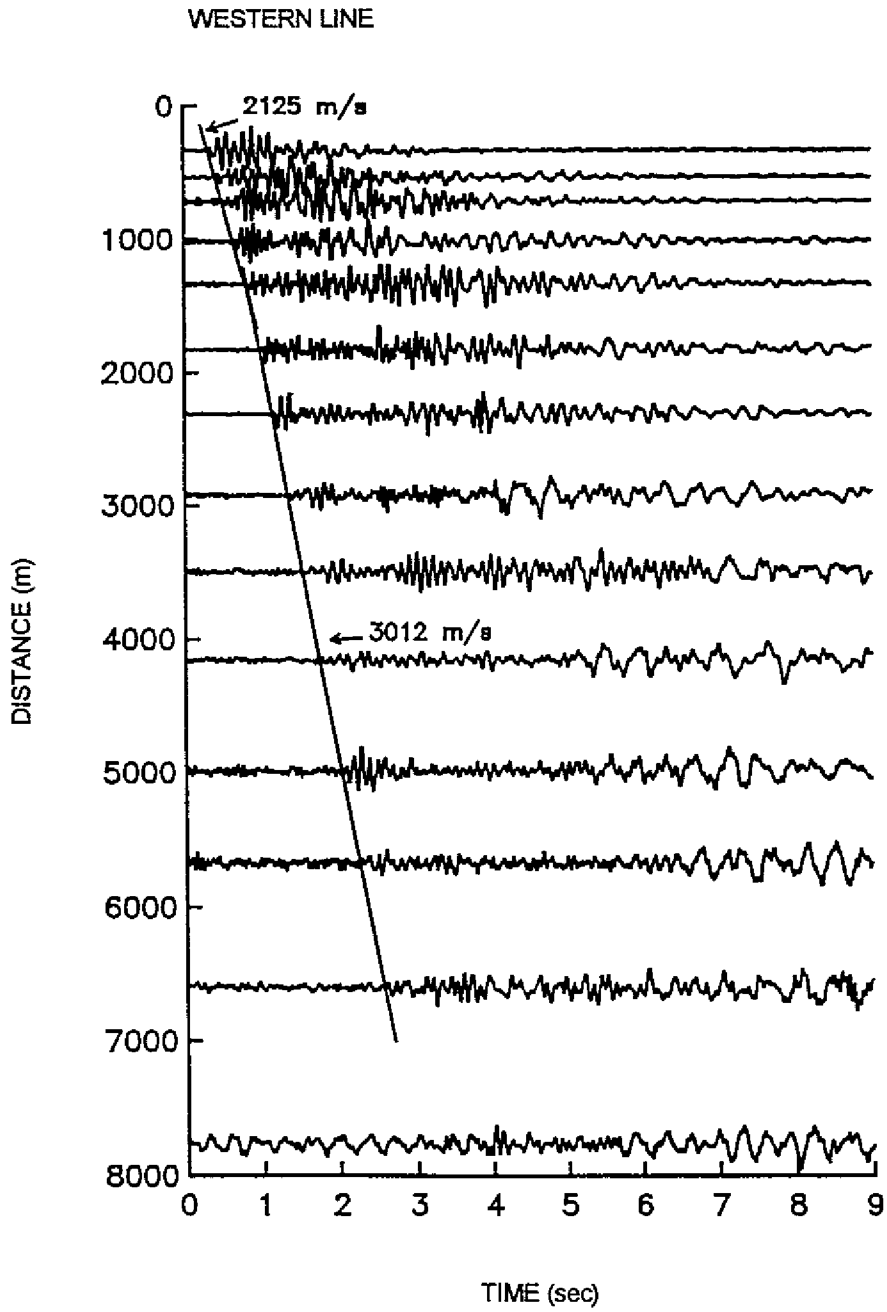


Fig. 3.2.2. Vertical traces for western line. Apparent velocities of P wave are shown for both first and second refractors.

3.3. COMPARISON OF GROUND VIBRATION CHARACTERISTICS ALONG SEVERAL DISTRICTS MAINLY WITH MICROTREMOR MEASUREMENTS

Kazuo Seo

The characteristics of strong ground motion during earthquakes are approximately understood, as the composition of effects due to (1) the seismic source mechanism, (2) the attenuation of the propagating waves and (3) modification of seismic waves due to local soil conditions. But it is also true that there is some confusion and sometimes misleading discussion in evaluating strong motions. These tendencies seem to reflect the fact that the effects of local soil conditions on strong motions, the third item, differ entirely from site to site. The authors believe that the Mexico Earthquake of 1985 and the Loma Prieta, California, Earthquake of 1989 provided valuable occasions to discuss this problem scientifically, although there were great sacrifices in the disaster areas.

The purpose of this paper is to compare local soil conditions among several different districts and to discuss the results as a fundamental study for establishing a seismic microzonation methodology. For this purpose, microtremor measurements were performed in several districts, because this seems to be one of the simplest methods for the relative evaluation of local soil conditions.

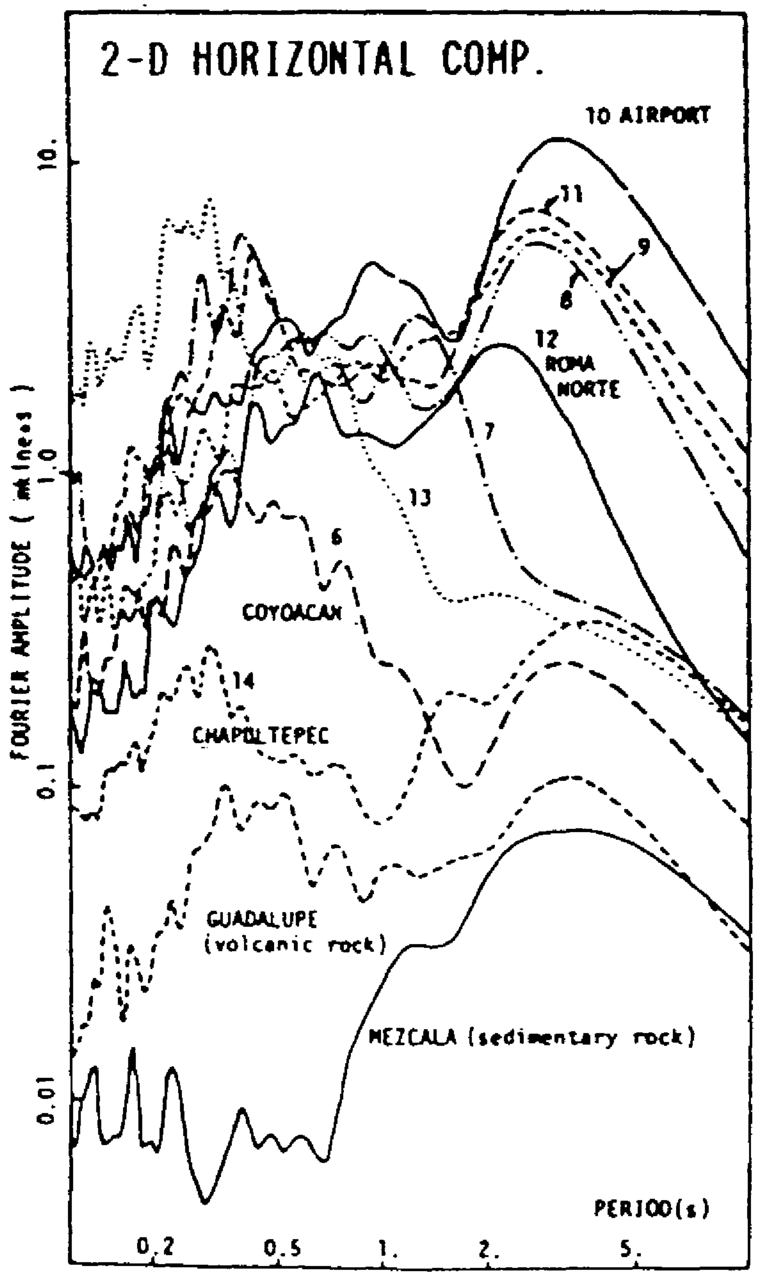


Fig. 3.3.1. Fourier spectra of measured microtremors in and around Mexico City

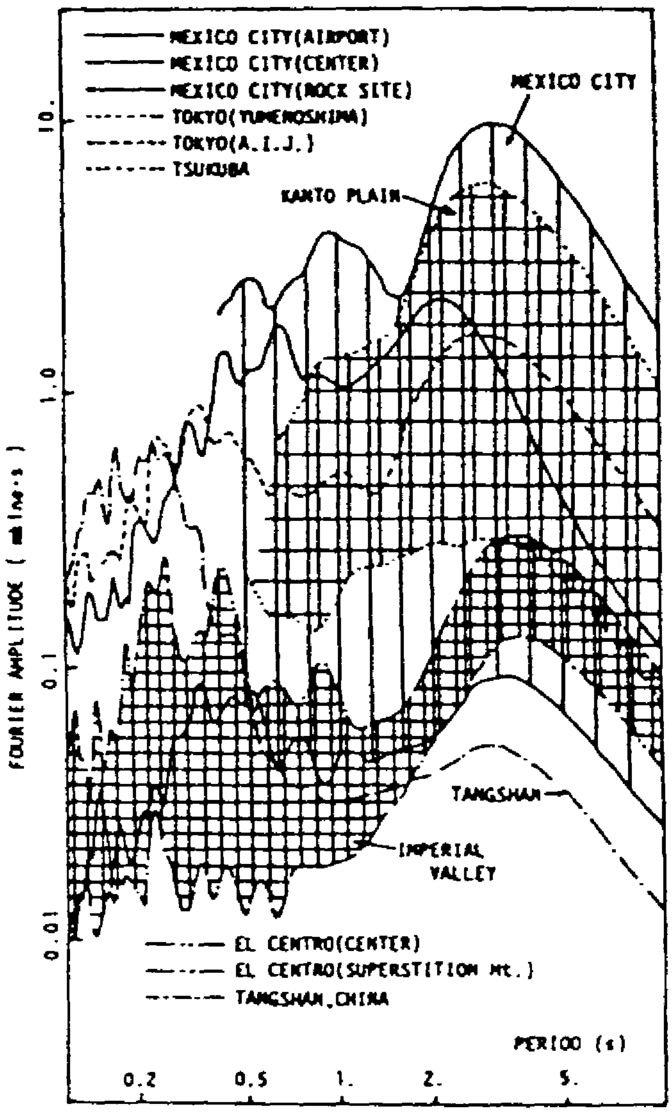


Fig. 3.3.2. Comparison of the results as a whole [T=5s, Disp. of 2-D Horiz, D=20s, dt=0.01s]

3.4. SEISMIC MICROZONATION IN COLIMA CITY

Kazuaki Masaki and Carlos Gutiérrez

In order to estimate basic parameters for seismic microzoning in Colima city, microtremors were observed at 57 sites in the urban area and 10 moderate magnitude earthquakes were recorded in soft and hard soils, information that was used to define isoperiod lines and amplification factors, respectively.

Additionally, microtremors were recorded along a 24 km line across the valley with limestone outcrops at both edges. It permitted to recognize the main differences in depth and dynamic behavior of the materials.

Finally, at two sites with representative lithology of the zone with the greatest number of human settlements, P and S wave velcities were directly observed using a logging system in boreholes with depths of 50 m; this permitted to propose a two-layer model for Colima city.

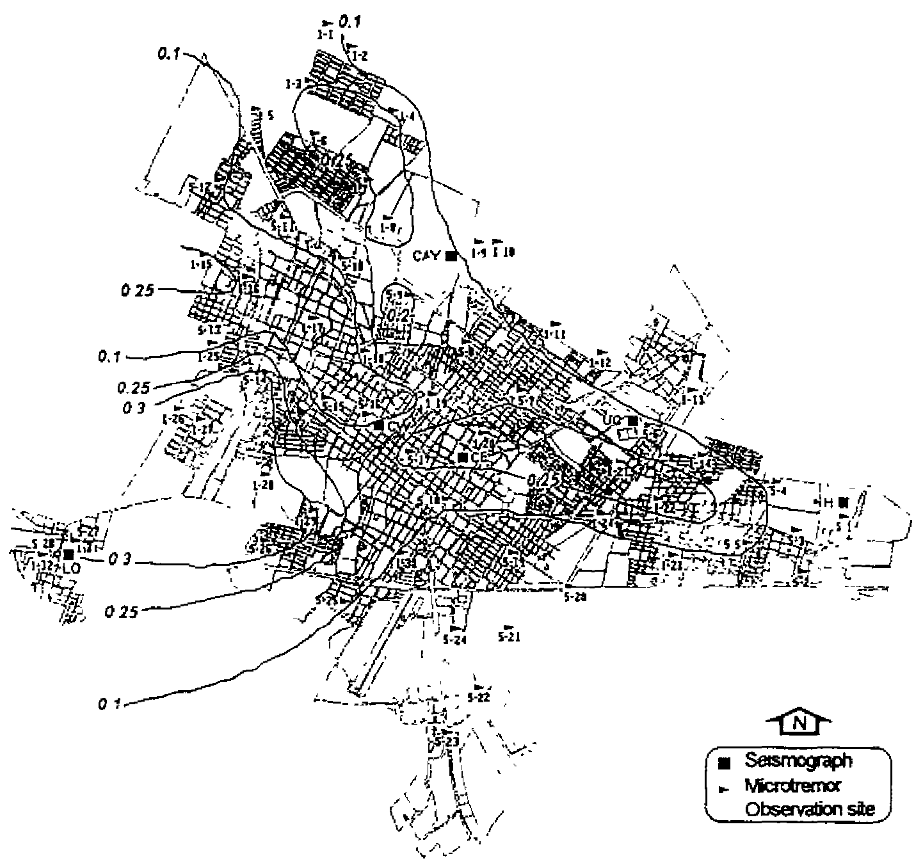


Fig. 3.4.1. Isoperiods map obtained from microtremor analysis. The first digit indicates the natural period of the sensor used at the site

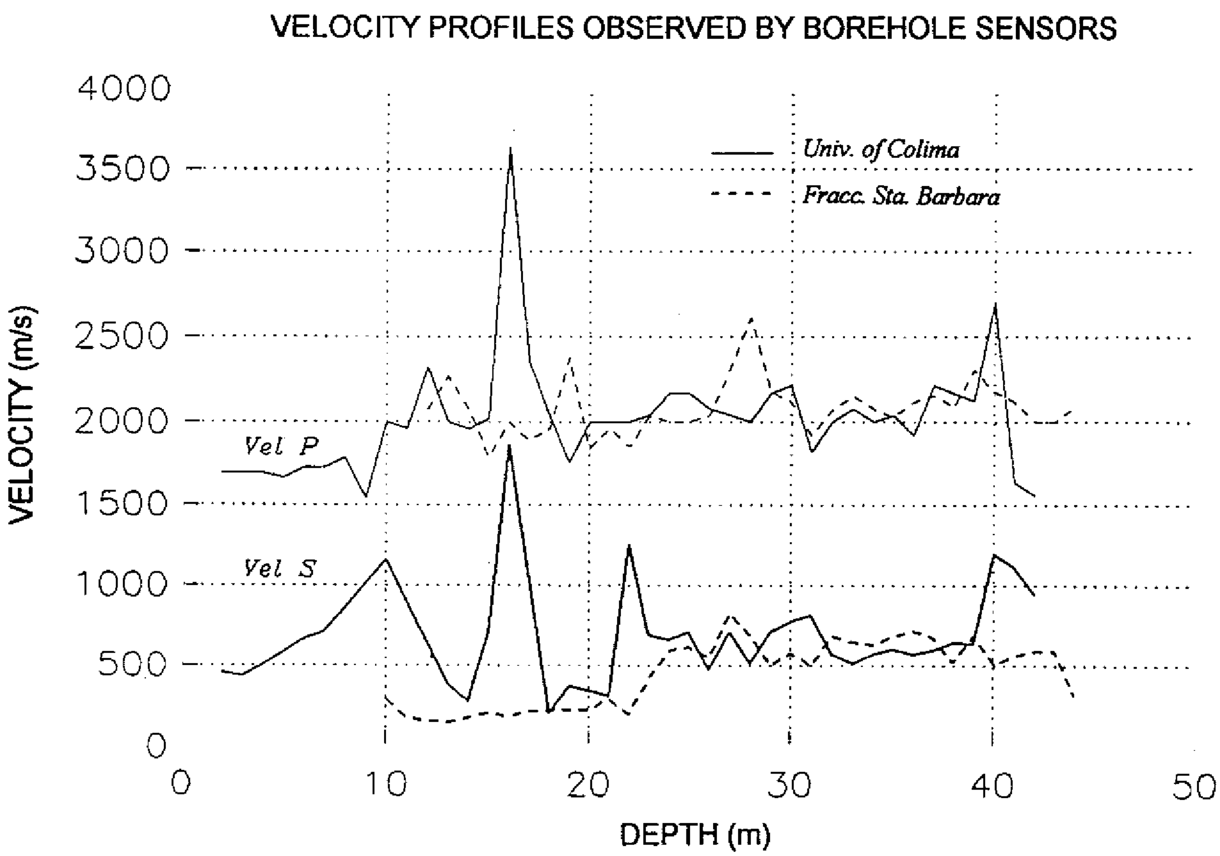


Fig. 3.4.2. P and S waves velocity profiles at two sites in Colima city

3.5. IS THERE TRULY A "HARD SITE" IN THE VALLEY OF MEXICO?

Shri Krishna Singh, Roberto Quaas, Mario Ordaz, F. Mooser, David Almora, Miguel Torres and Ricardo Vázquez

To understand the cause of observed amplification of seismic waves even at hill-zone sites in the Valley of Mexico, sensitive digital accelerographs have been installed at three especially chosen sites. Two of these sites, MADI and TEXC, located on hard Oligocine andesites, were expected to be free of site effects. Analysis of the data recorded by these and other accelerographs during three moderate, shallow subduction zone events, however, shows significant amplification at MADI and TEXC between 0.2 and 0.6 Hz. The cause of the amplification at hill-zone sites in the Valley of Mexico, including MADI and TEXC, may be pervasive low shear-wave velocity in, and complex structure of, the upper layers of volcanic rocks. If so, then there may not be a truly "hard" site in the valley.

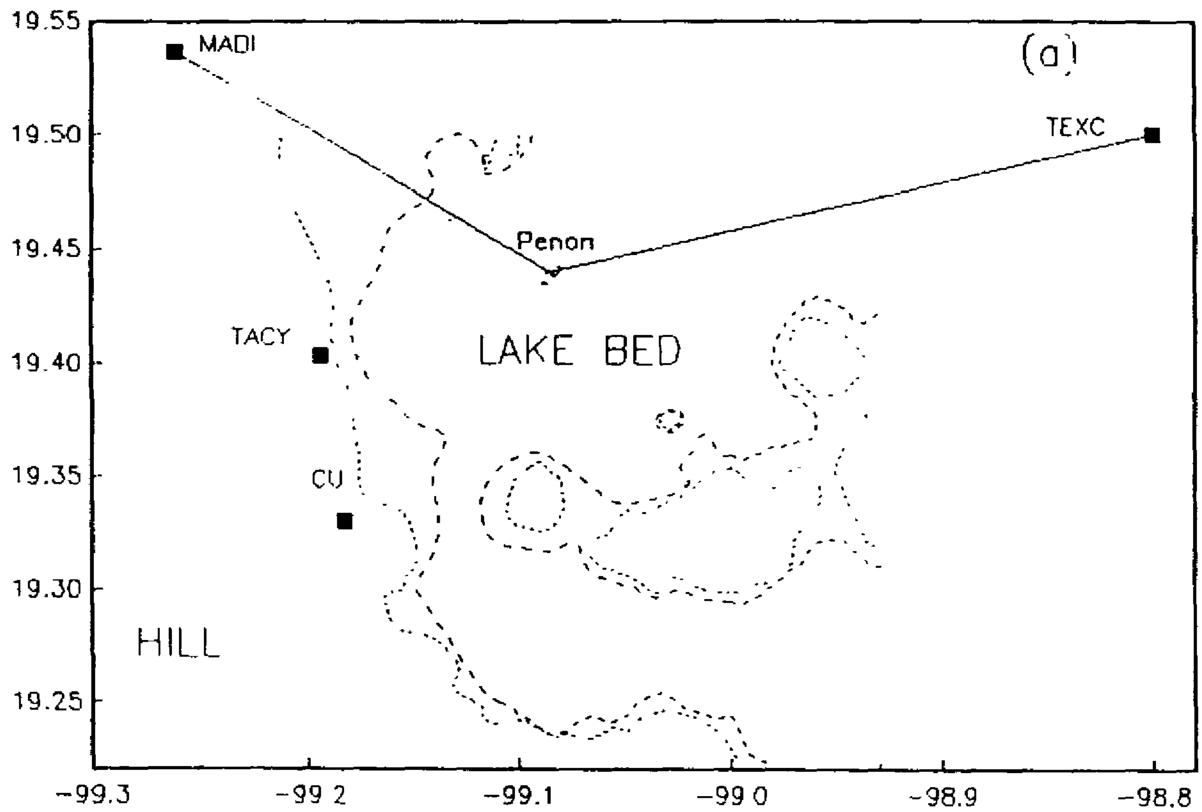


Fig. 3.5.1. Geotechnical map of a part of the Valley of Mexico showing boundary between hill and transition zones (dotted) and between transition and lake-bed zones (dashed).

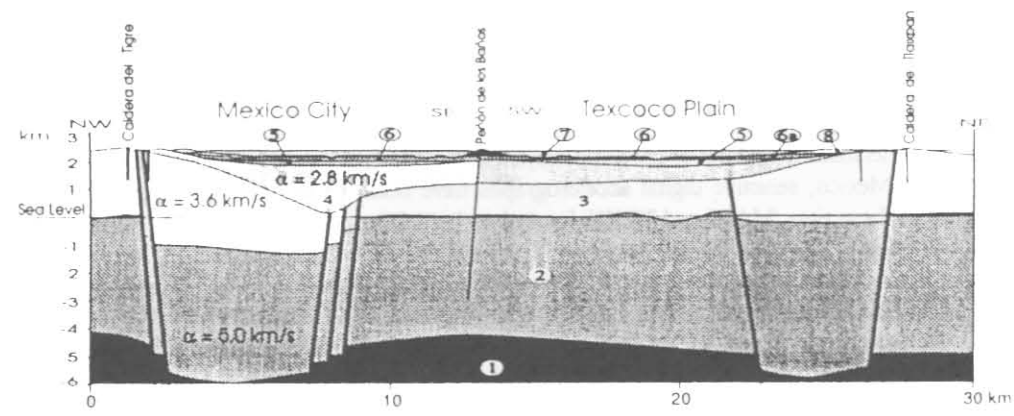


Fig. 3.5.2. Geological section from MADI to Peñon to TEXC (after Mooser et al., 1994). α = P-wave velocity. 1: Mesozoic metamorphics. 2: Upper Mesozoic marine deposits. 3: Ologocene volcanics. 4: Miocene volcanics. 5: Pliocene lake deposits. 6: Tepozteco clastics. 6a: Sierra Patlachique clastics. 7: Turbidites and recent lake deposits. 8: Volcanic fans.

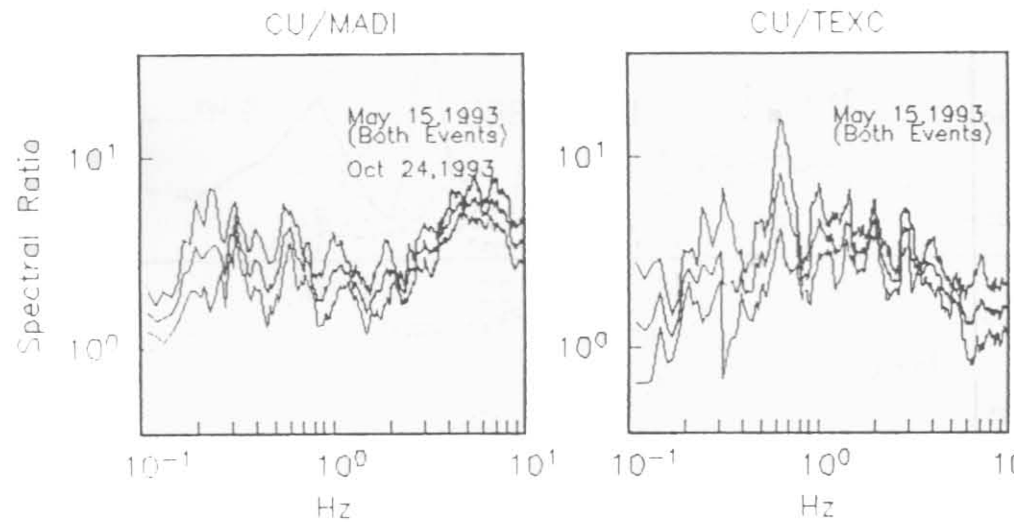


Fig. 3.5.3. Spectral ratio at CU with respect to MADI (left) and TEXC (right). Geometric mean and 16 and 84 percentile curves are shown. Both horizontal components were used in the computation.

3.6. A STATISTICAL METHOD FOR THE INVESTIGATION OF SITE EFFECTS BY MEANS OF DOWNHOLE ARRAY - SH AND LOVE WAVES -

Shigeru Kinoshita

A purpose-built method for the investigation of the site effects by means of downhole array observation is proposed This method is based on a statistical time series model which is applicable to the transverse component recordings simultaneously obtained on a free field and at a depth The time series model can take in not only the amplitude but also phase characteristics of the recordings. By applying the method to actual downhole array recordings, the following aspects of the site effects are investigated. Namely, the estimation of a transfer function, the separation of the upcoming and downgoing waves from the downhole seismogram, and the enhancement of fundamental mode Love-wave on a free surface are practically examined. A point worthy of notice is that these aspects of the site effects are calculated without using the knowledge of the velocity structure beneath the site.

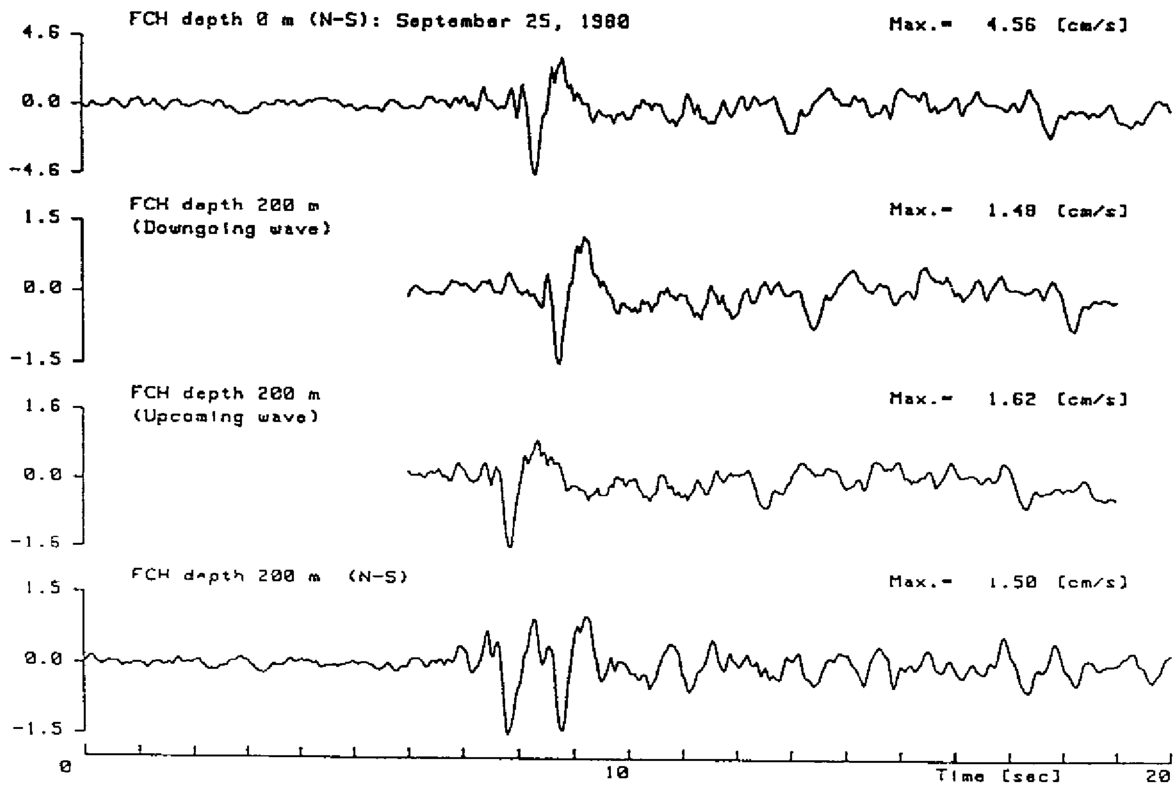


Fig. 3.6.1. The separation of the upcoming and downgoing waves at a depth of 200 m. (Top) Velocity on a free surface; (Middle) Calculated upcoming and downgoing waves at a depth of 200 m; (Bottom) Velocity at a depth of 200 m at the Fuchu site for the Central Chiba earthquake of 25 September 1980.

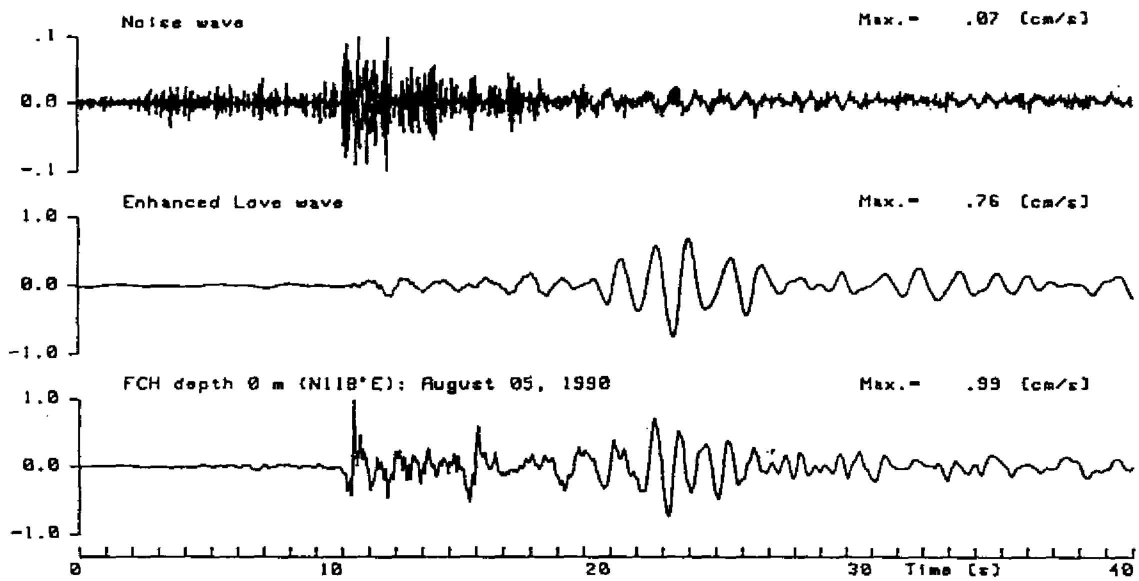


Fig. 3.6.2. The enhancement of fundamental mode Love-wave.
(Top) Noise wave on a free field; (Middle) Enhanced Love wave; (Bottom) Velocity on a free surface at the Fuchu site for the Hakone Region earthquake of 5 August 1990

3.7. ANALYSIS OF THE BORE-HOLE RECORDINGS OBTAINED IN MEXICO CITY DURING THE MAY 31, 1990 EARTHQUAKE

Mario Ordaz, Miguel Santoyo, Shri Krishna Singh and Roberto Quaas

We analyze bore-hole recordings obtained at different sites of the Valley of Mexico during the May 31, 1990, earthquake (Ms=5.8). Recording sites consist of two or three three-component digital accelerographs, located on the surface and at different depths, depending on the subsoil characteristics. Detailed stratigraphic profiles of the sites, including S-wave velocity measurements, are available. We performed 1D elastic propagation analysis assuming vertical incidence of shear waves, both in the frequency and in the time domains, considering that the recorded time histories describe not the incident but the complete wavefield.

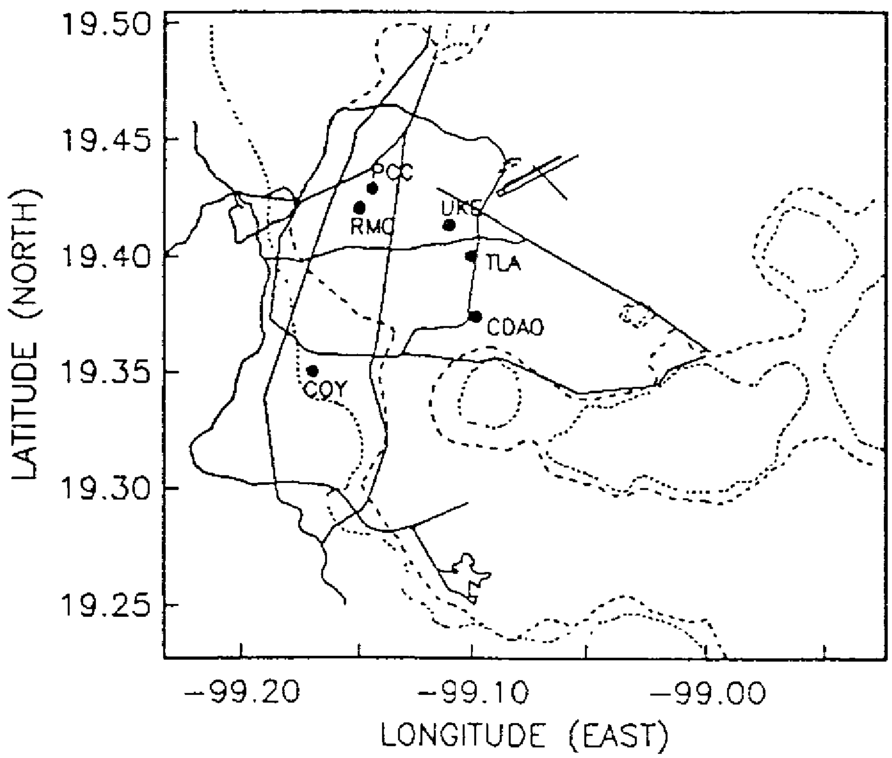


Fig. 3.7.1. Mexico City geotechnical zonification and bore-hole stations

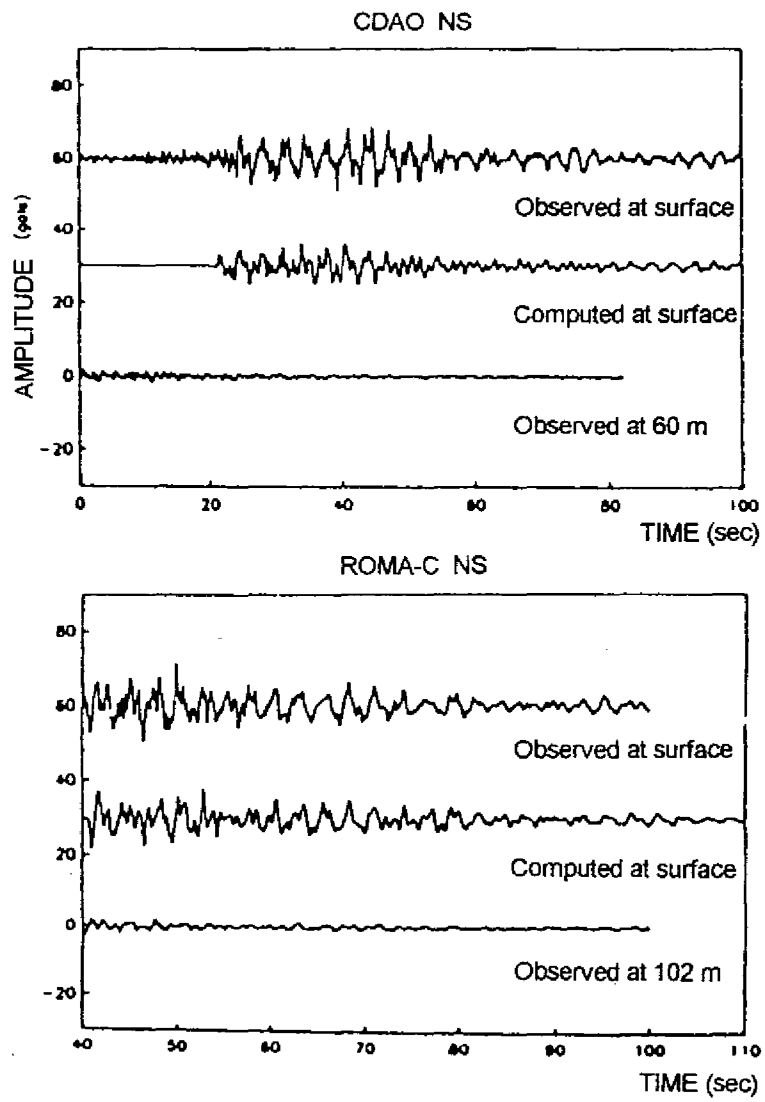


Fig. 3.7.2. Synthetic (middle) and observed (top & bottom) accelerograms

3.8. INTERPRETATION OF WAVE FIELD INSIDE THE MEXICO VALLEY ON THE BASIS OF BOREHOLE DATA

Masahiro Iida, Mario Ordaz, Hitoshi Taniguchi, Carlos Gutiérrez and Miguel Santoyo

The 19 September 1985 Michoacan earthquake (Ms=8.1) caused very severe damage in Mexico City inside the Mexico Valley, which is approximately 400 km from the epicenter in the Pacific Ocean. Seismic waves were amazingly amplified inside the valley, especially in the lake-bed zone, and the long duration of the lake-bed seismogram was a real surprise.

In the present study, we perform (1) the evolutionary spectrum analysis, (2) the 1-D elastic propagation analysis and (3) the cross correlation analysis for borehole data. Although the period of dominant waves varies from site to site in the lake-bed zone, the seismograms are composed of both surface waves and long-period body waves. They can be caused by the very soft surficial layers. The long coda of the seismograms seems to be produced by the multipathing due to the long-distance path.

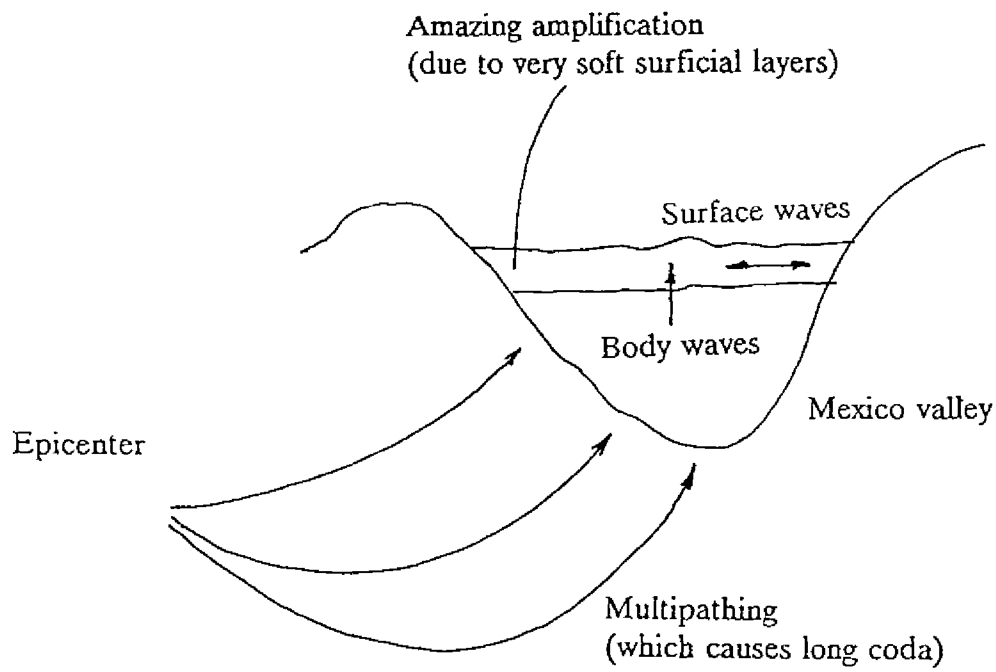


Fig. 3.8.1. Schematic display explaining wave-propagation mechanism of producing lake-bed seismograms

3.9. ON THE ORIGIN OF LONG CODA OBSERVED IN THE LAKE-BED STRONG-MOTION RECORDS OF MEXICO CITY

Shri Krishna Singh and Mario Ordaz

As expected, the characters of accelerograms in the hill zone and lake-bed zone are widely different; apart from amplitude and frequency content differences, the former seldom exceeds 60 sec in duration, whereas the latter reaches 200 sec during large earthquakes. Despite many attempts to model accelerograms in Mexico City, no satisfactory explanation has been offered for the long coda seen in lake-bed records, which manifests itself in a succession of roughly harmonic beats of slowly decaying amplitude. One-dimensional idealizations of subsurface structure of the lake-bed zone, when excited by a hill-zone record, fail to increase the duration appreciably (e.g., Sánchez-Sesma *et al.*, 1988; Kawase and Aki, 1989). This can be appreciated from Fig. 3.9.2, where we show observed radial accelerograms at CU (Ciudad Universitaria, a hill-zone site) and Station 56 (a lake-bed site, see Fig. 3.9.1 for location of recording sites) during the San Marcos earthquake of 25 April 1989 (Ms=6.9). The figure also shows the synthesized ground motion at 56 using CU record as input to a 1-D vertical SH-wave propagation model. It is at once clear that: (1) the duration of the simulated record at 56 is less than half of the observed one; and (2) the observed trace at 56 shows harmonic beating.

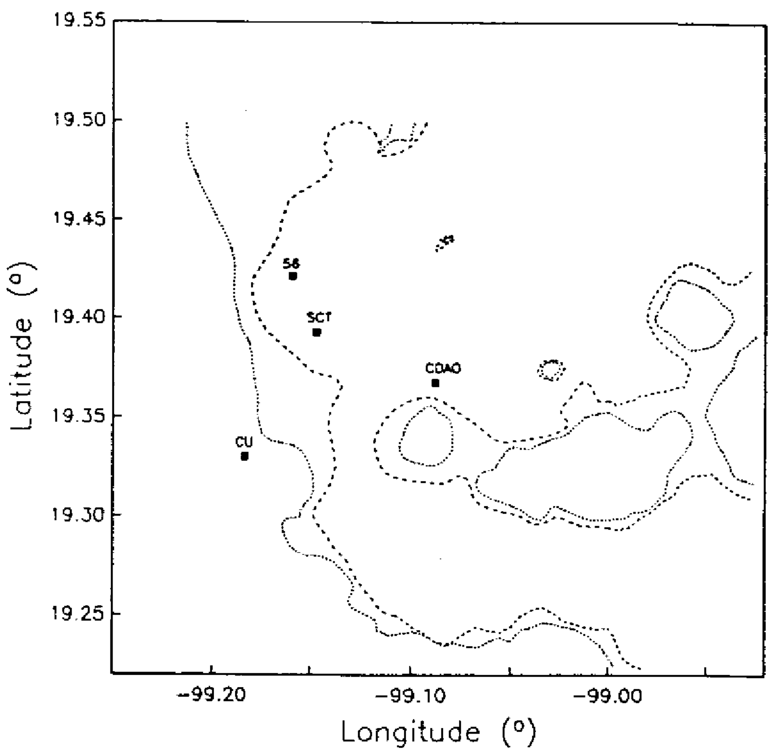


Fig. 3.9.1. Map of Mexico City showing boundary between hill and transition zones (dotted) and between transition and lake-bed zones (dashed). Location of broadband stations at CU (a hill-zone site) and the three strong-motion lake-bed sites are marked.

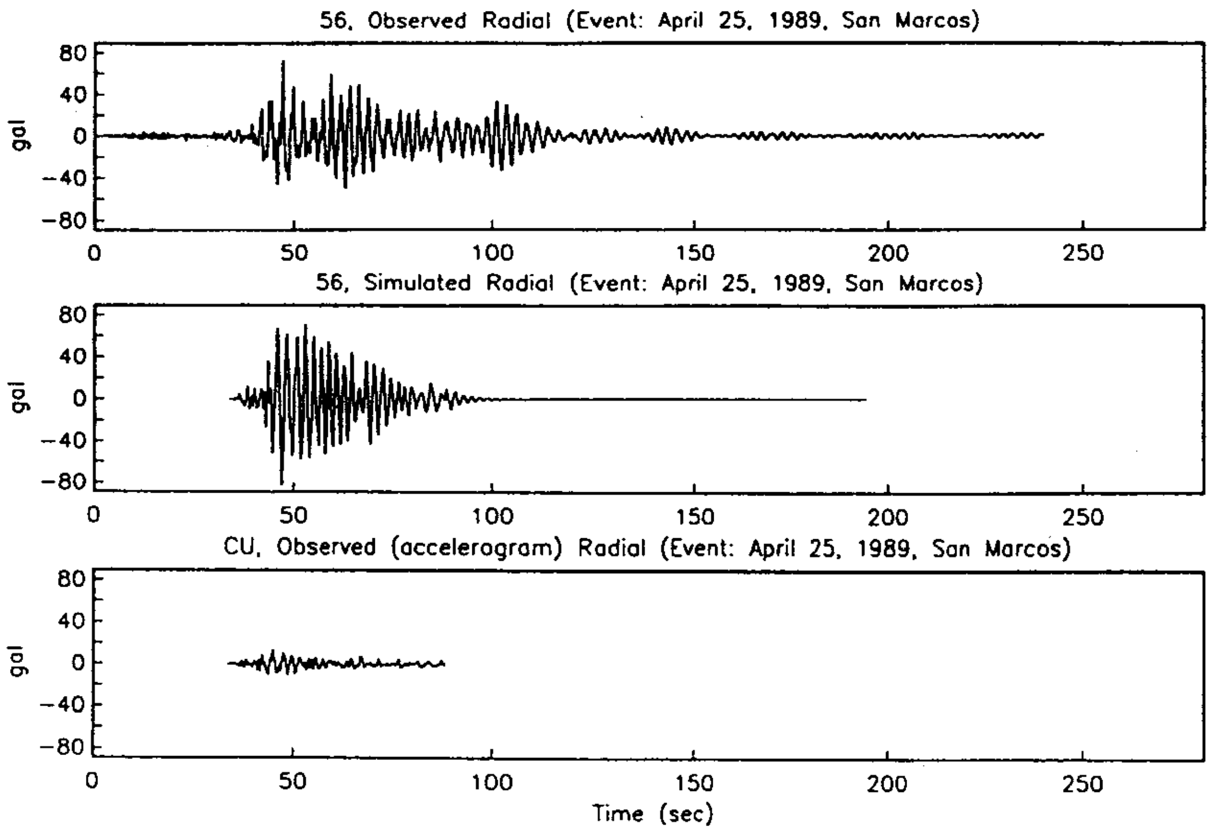


Fig. 3.9.2. [Bottom frame]: Radial accelerogram recorded at CU during the 25 April 1989 (Ms=6.9) event. [Middle frame]: Synthesized accelerogram at site 56, computed using 1D vertically propagating SH-wave model. [Top frame]: Observed accelerogram at site 56. Note the difference in duration between middle and upper frame.

3.10. A STUDY ON THE RESPONSE OF A SOFT BASIN FOR INCIDENT S, P AND RAYLEIGH WAVES WITH SPECIAL REFERENCE TO THE LONG DURATION OBSERVED IN MEXICO CITY

Hiroshi Kawase and Keiiti Aki

The numerical methods to calculate the ground motions in the sedimentary basins and fundamental features of their responses are reported. First, to understand the fundamental characteristics of the responses for a basin with a simple shape, trapezoidal basin responses are studied by the Boundary Element method. The results show that surface waves generated at the edges of the basin are clearly propagating inside the basin back and forth to increase the duration up to 20 seconds. Then, more realistic three-layered basin model shown in Fig. 3.10 1 is used to see the effects of soft surface layers. As shown in Fig. 3.10.2 we found in this case that the calculated durations and envelope shapes become very similar to the observed ones because of the slowness of surface wave propagation. These results suggest that the exceptionally long duration observed in Mexico City might be caused by a strong, constructive interaction of soft-surface layers with a deep basin structure beneath the city.

Another evidence of an important role of basin-induced surface waves is reported from Ashigara Valley observation in Japan. The observed strong motion characteristics are tried to be simulated by a 2-D Finite Element method. The matching between observation and simulation is qualitatively good but quantitatively need to be improved. These simulation studies suggest the importance of geological and geophysical information of basin structures for a quantitative simulation Other recent numerical studies are also reviewed.

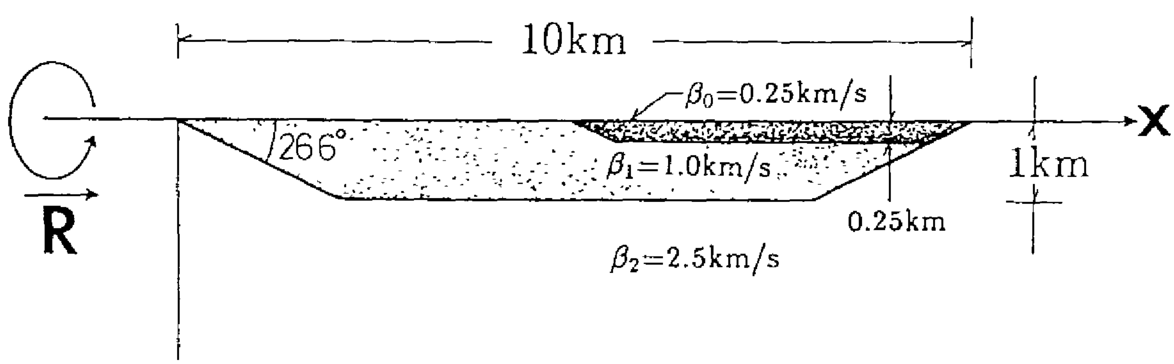


Fig. 3.10.1. Simplified basin model with a soft surface layer inside

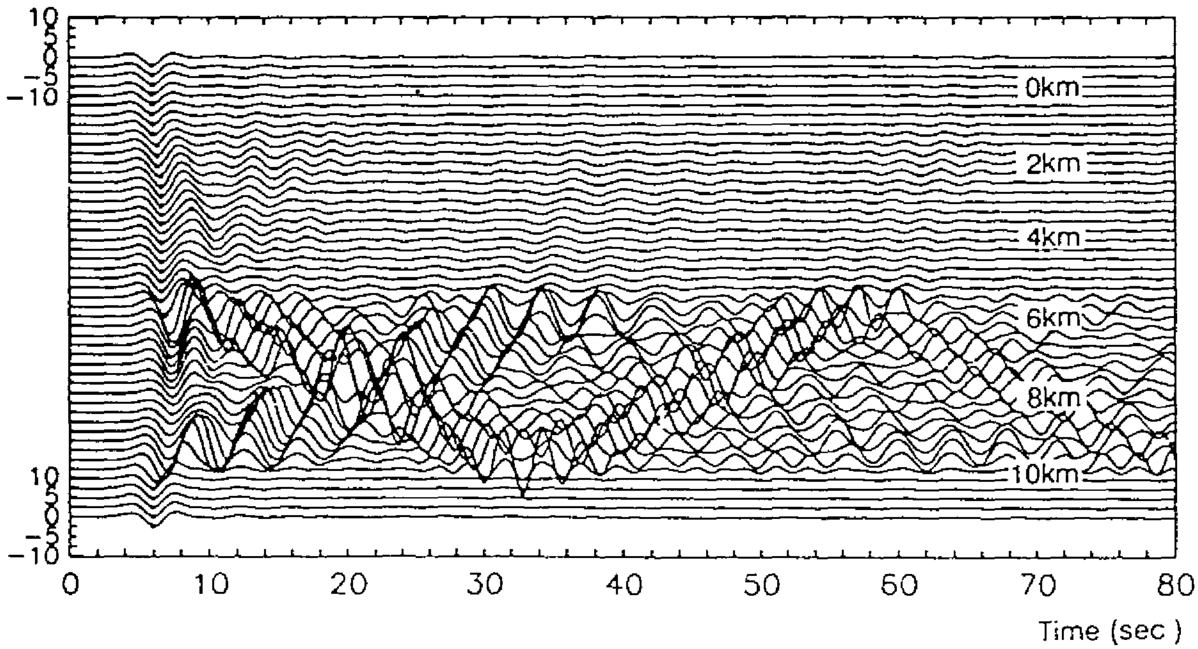


Fig. 3.10.2. Responses on the surface of the basin shown above to an incident SH wave