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INTERPRETATION OF WAVE FIELD INSIDE THE MEXICO VALLEY BASED UPON BOREHOLE DATA

Masahiro IIDA*, Mario ORDAZ**, Hitoshi TANIGUCHI***, Carlos GUTIERREZ** and Miguel SANTOYO**

* Earthquake Res. Inst., University of Tokyo, Tokyo 113, Japan.
** National Disaster Prevention Center, Mexico D.F. 04360, Mexico.
*** United Nations, Centre for Regional Development, Nagoya 450, Japan.

ABSTRACT

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 lakebed zone, and the long duration of the lakebed seismograms was a real surprise. In the present study, the following analyses were performed: (1) the evolutionary spectrum analysis, (2) the 1-D elastic propagation analysis and (3) the cross correlation analysis for the borehole data. Although the period of dominant waves varies from site to site in the lakebed zone, the seismograms are composed of both surface waves and long-period body waves. The period of dominant waves can be caused by the very soft surficial layers. The long coda of the seismograms seem to be produced by multipathing due to the long-distance path.

KEYWORDS

Lakebed zone; anomalous amplification; long duration; soft surficial layers; long-distance path; wave field; borehole seismograms; cross correlation analysis.

INTRODUCTION

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. The Mexico Valley is divided into three zones, namely; the hill zone, the transition zone, and the lakebed zone (Fig. 1). Whereas the earthquake produced very low accelerations at epicentral stations, seismic waves were amazingly amplified inside the valley, especially in the lakebed zone, and the long duration of the lakebed seismograms was a real surprise (Fig. 2).

Many researchers thought that the origin of long coda seen in the lakebed zone was surface waves due to the deep Mexico basin and the soft surficial layers (Bard *et al.*, 1988; Sanchez-Sesma *et al.*, 1988; Kawase and Aki, 1989). This opinion seems to be right in part. However, Chavez-Garcia (1991) showed that this interpretation was not viable unless the shear-wave Q in the lakebed sediments was extremely high.

Another possible cause for the long coda is the long-distance path from the earthquake source to the Mexico Valley. Campillo *et al.* (1988) pointed out the complexity of incident wavefield into the deep basin and interpreted the wavefield as regional body waves. Singh and Ordaz (1993) found that broadband seismograms obtained in the hill zone of the Mexico Valley also had long coda.

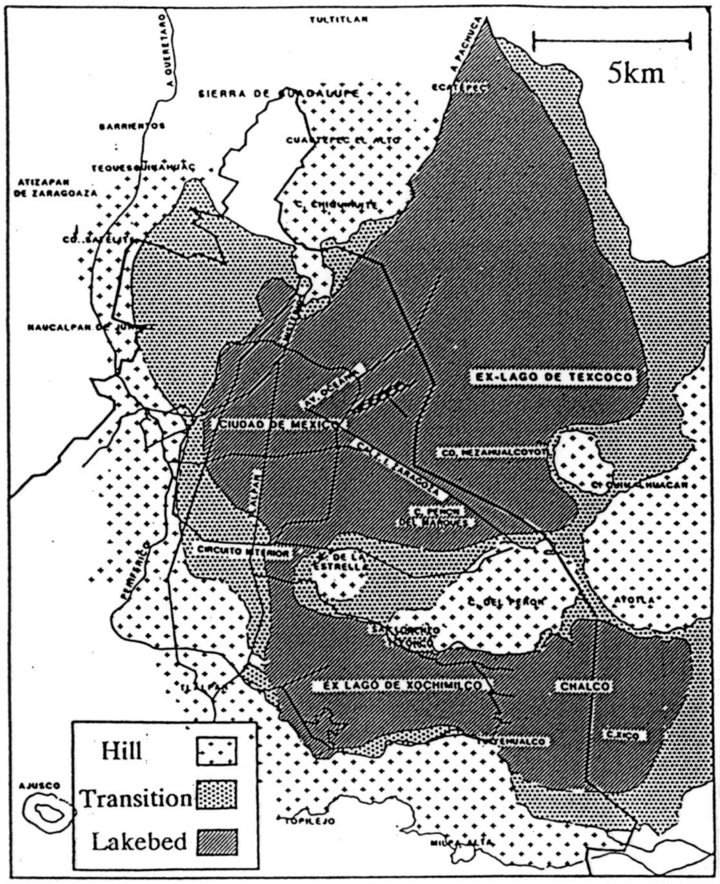

Fig. 1. Location map of the Mexico Valley showing hill, transition and lakebed zones.

It is sure that large nonlinear behavior is not expected in Mexico City, because the main surface material is clay and because small nonlinear behavior was recognized at only one station even during the great 1985 earthquake (Singh *et al.*, 1988).

STRONG-MOTION DATA

A strong-motion network has been constructed by the National Disaster Prevention Center (CENAPRED) of Mexico under the support of the Japan International Cooperation Agency (JICA) project for the past several years. It is composed of 5 stations to investigate path effects from the Pacific Ocean to Mexico City and of 10 stations distributed inside the Mexico Valley, which might be used to study site effects in Mexico City. Fig. 3 shows the location of each station of the current network. One strong advantage of the network is that, in Mexico City, it has 6 borehole stations, with each station having 2 underground and 1 surface instruments. As of the end of 1993, the network had recorded 4 intermediate-sized earthquakes at most stations.

METHODS

In the present study, we hypothesize that the long coda in the lakebed zone are not only surface waves, but also long-period body waves, which are produced by multipathing due to the long-distance path and the very soft surficial layers. We performed the evolutionary spectrum analysis (Kameda, 1975), the 1-D elastic propagation analysis and the cross correlation analysis for the borehole data (Satoh *et al.*, 1993).

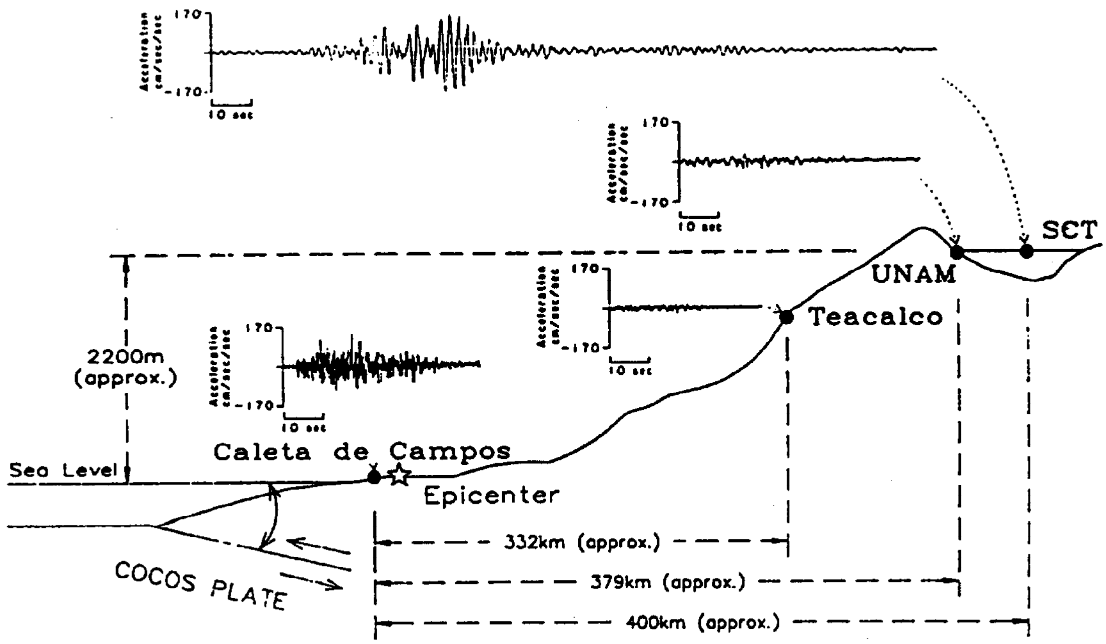

Fig. 2. Schematic section showing relative locations of the epicentral station at Caleta de Campos, Teacalco station (closest to Mexico City), and Mexico City stations, UNAM (hill zone) and SCT (lakebed zone). The seismograms are east-west components of 19 September 1985 acceleration time-histories (all plotted to the same scale) (after Celebi *et al.*, 1987).

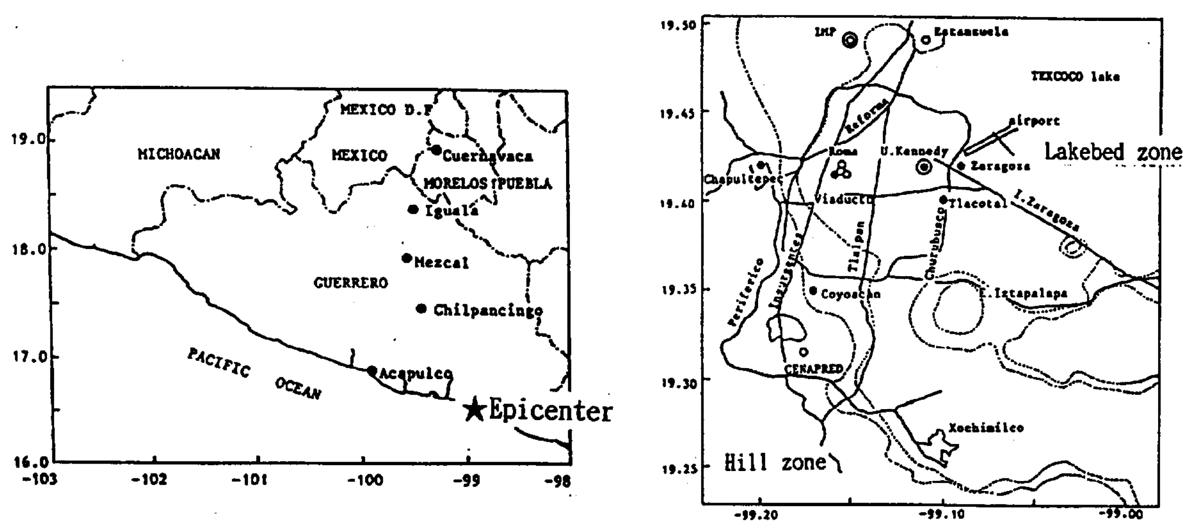

Fig. 3. Epicenter location (shown by star) for the 24 October 1993 earthquake and station locations of the CENAPRED strong-motion network. It is composed of 5 stations of the attenuation line and of 10 stations distributed inside the Mexico Valley.

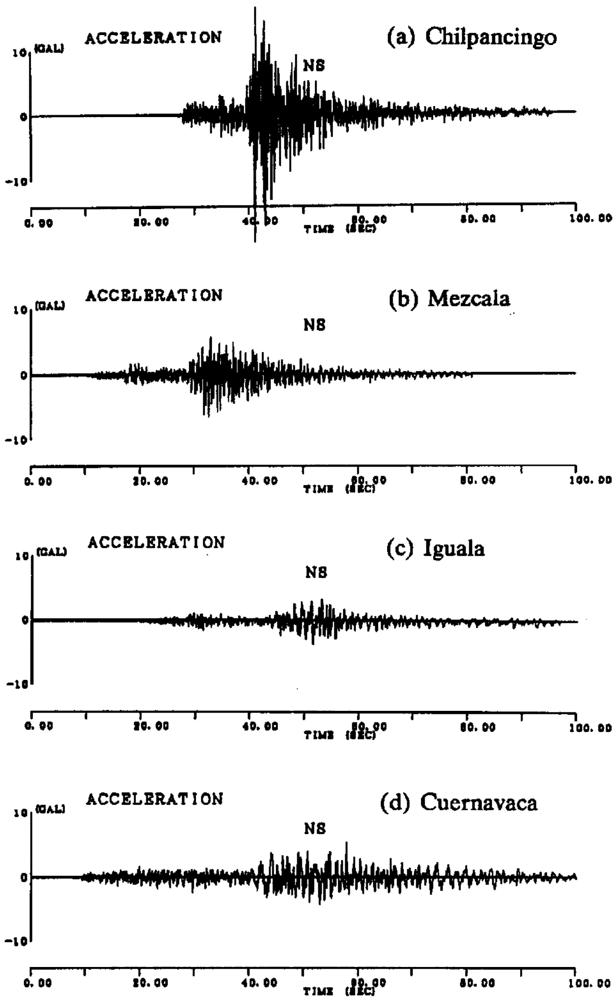

Fig. 4. North-south components of strong-motion accelerograms from the October 24, 1993 earthquake (M=6.7) at 4 stations of the attenuation line. The record (d) at the Cuernavaca station, which is located just outside the Mexico Valley, has long duration.

Many researches have been concentrated on the great 1985 earthquake. To identify path, deep basin, and local site effects, however, use of small earthquakes is desirable because the source effects are simple. The recent earthquake of October 24, 1993 (M=6.7) turned out to be satisfactory on this condition by strong-motion records at the Chilpancingo station (Fig. 4(a)). The seismograms observed at the Cuernavaca station, which is located just outside the Mexico Valley, imply that the incident wavefield is actually complex (Fig. 4(d)). The records of the attenuation line suggest the presence of multipathing effects due to the long-distance path.

There were no borehole records during the 1985 great earthquake. Ordaz *et al.* (1992) showed that the main parts of records behave like body waves even at the lakebed stations, through a 1-D analysis of borehole recordings of the May 31, 1990 earthquake. But, owing to the low amplitude level (Ms=5.8), later phases were not well recorded. On the other hand, the borehole records from the 24 October 1993 earthquake (M=6.7) at the Tlacotal station have long-duration (Fig. 5), so that we analyze these recordings here. The underground profile at the site is primarily characterized by the very low S-wave velocity and the extremely low density close to 1.0 gr/cm^3 in the upper 50 m (Fig. 5).

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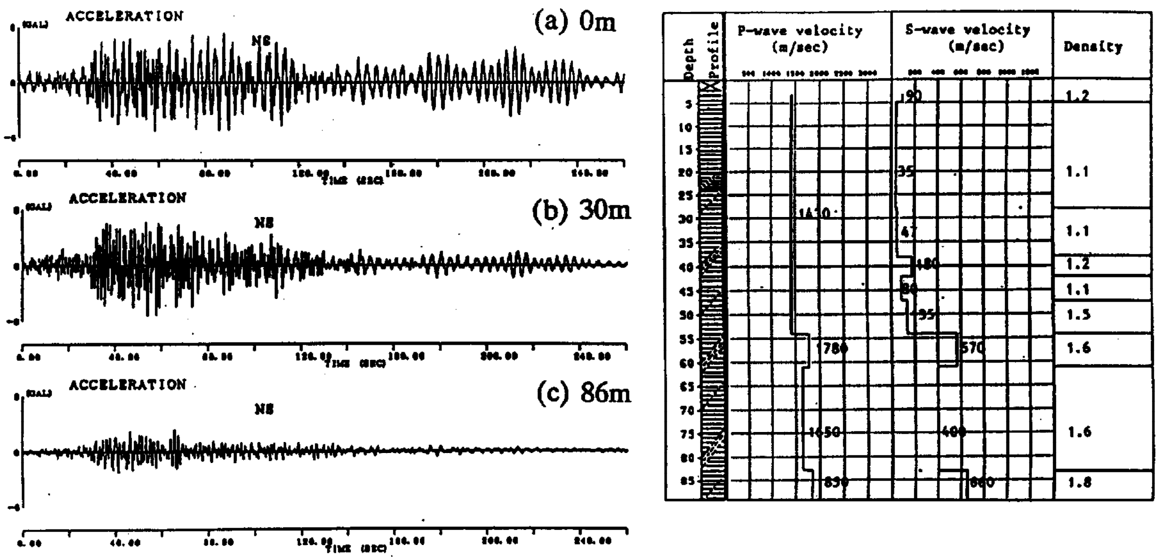
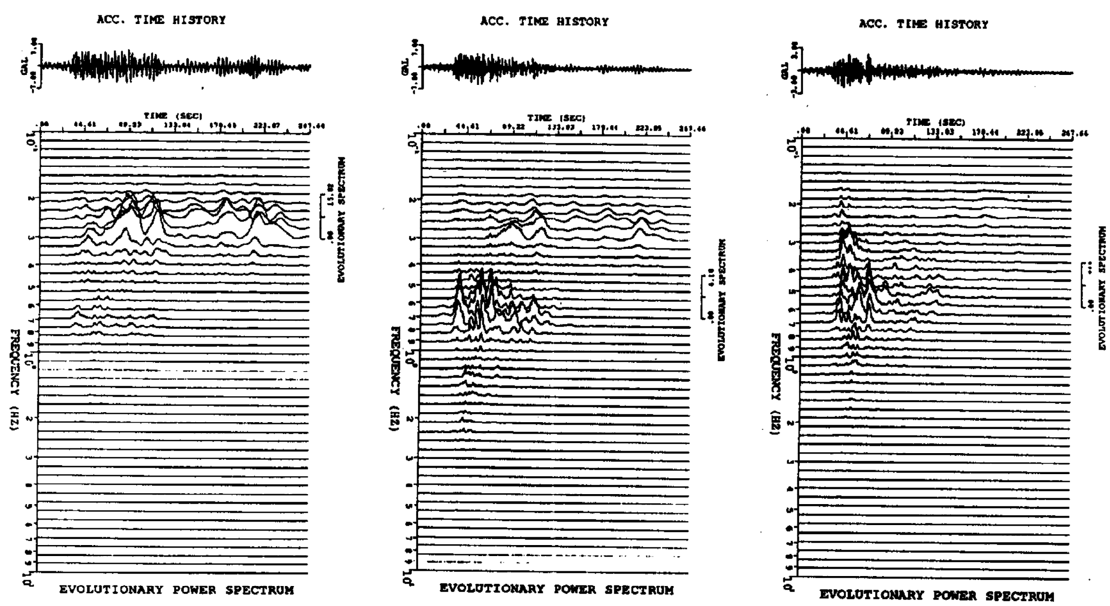


Fig. 5. North-south components of strong-motion accelerograms from the October 24, 1993 earthquake (M=6.7) and stratification profile at the Tlacotal borehole station in the lakebed zone of Mexico City.



(a) 0m (b) 30m (c) 86m

Fig. 6. Evolutionary spectra for north-south components recorded at the Tlacotal borehole station.

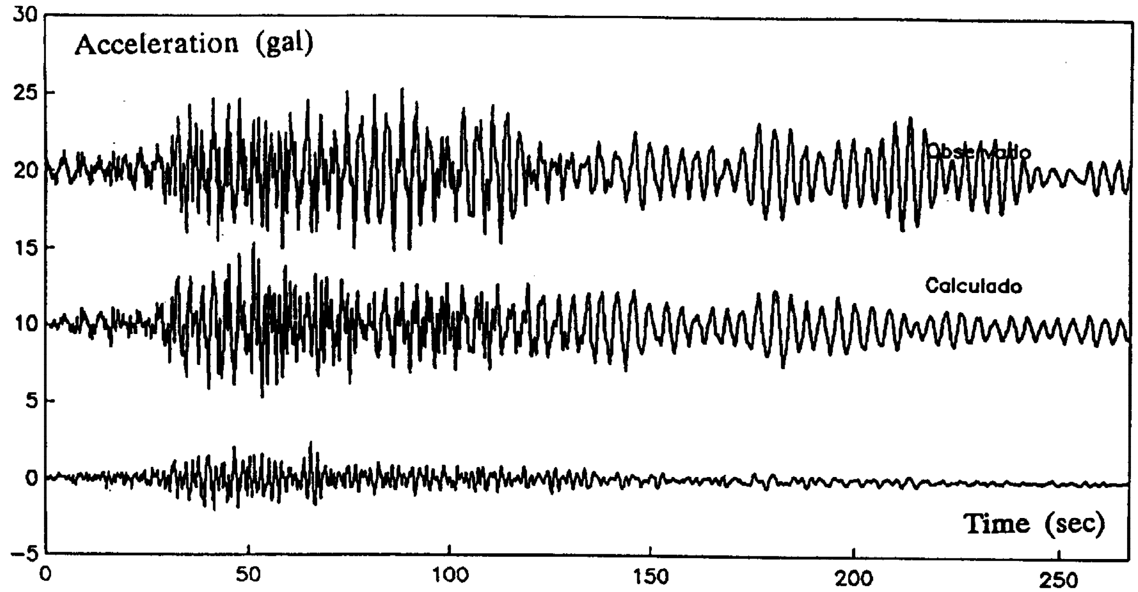


Fig. 7. Comparison of surface observed data and synthetic at the Tlacotal borehole station. The upper and middle traces mean the observational and synthetic seismograms of north-south components. The lower trace is the observational seismogram of the same component at a depth of 86 m.

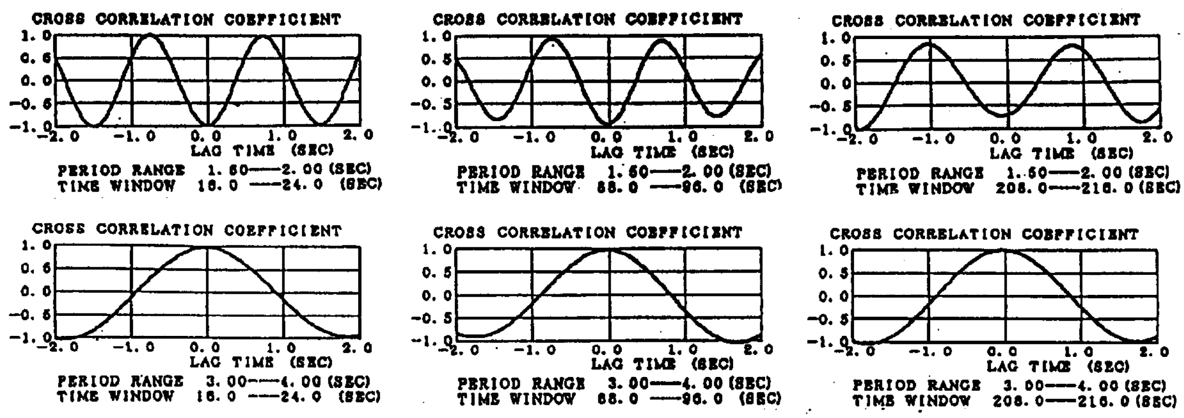


Fig. 8. Cross correlation coefficients between surface and 30m-depth seismograms of north-south components at the Tlacotal borehole station. These examples are shown for specific period ranges and time windows. No lag time means surface waves, while the 0.64 sec lag time corresponding to vertical S-wave propagation means body waves.

RESULTS

At first, we conducted the evolutionary spectrum analysis and found that the predominant period of the accelerogram at each depth was quite different. The predominant period was more than 3 sec on the ground surface while it was around 2 sec at a depth of 86 m (Fig. 6).

Secondly, we performed 1-D elastic propagation analysis, assuming vertical incidence of shear waves into the borehole bottom instrument. In this analysis, we achieved a good agreement between the surface synthetic and observed data (Fig. 7). This means that the surficial soft layers afford to cause the dominant waves seen in the surface records.

Thirdly, the cross correlation analysis for discriminating wave types indicates that, judging from the lag times, short-period waves less than 2 seconds of engineering significance are body waves while long-period waves more than 3 seconds are surface waves (Fig. 8).

CONCLUSIONS

Although the period of dominant waves varies from site to site in the lakebed zone of Mexico City, the seismograms are composed of both surface waves and long-period body waves. The period of dominant waves can be caused by the very soft surficial layers.

The long coda of the seismograms seem to be produced by multipathing due to the long-distance path. The seismograms observed at the Cuernavaca station, which is located just outside the Mexico Valley, imply that the incident wavefield is actually complex.

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