S-wave velocity structure of Mexico City obtained from three-component microtremor measurements and microtremor array measurements

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ABSTRACT: Three-component microtremor measurements and microtremor array measurements have been performed at 6 points in central Mexico City. The microtremor array measurements used 25 to 650m triangular arrays and clear dispersion curves were obtained between 0.3 and 10 Hz. The peak frequencies of the horizontal and vertical ratio (H/V) of spectra vary from 0.25 to 2Hz. A joint inversion of an H/V spectrum and a dispersion curve is applied to observed data and S-wave velocity models down to a depth of 200m were obtained. A low velocity layer with S-wave velocity lower than 150m/s existed at a depth of 70m at the middle of the Mexico basin. It seems that the peak frequency of 0.25Hz in the H/V spectra is due to this shallow low velocity layer.

1 INTRODUCTION

The earthquake that struck Mexico on 19 September 1985 caused severe damage in Mexico City although the city is located 400km from the epicenter. The main reason for this is that the city is located on a basin filled with very soft sediments (Abe, 1986). Distribution of these soft sediments has been delineated by drillings and microtremor measurements (Lermo and Chavez-Garcia, 1994). A small number of attempts have been made to image the S-wave velocity structure of the basin using downhole seismic loggings. In order to delineate S-wave velocity structure of the basin down to depth of approximately 200m, we have performed three-component micro-tremor measurements and microtremor array measurements.

2 INVESTIGATION SITE

The investigation site is placed at the downtown of Mexico City. The three-component microtremor measurements were performed at more than 10 sites and the microtremor array measurements were performed at 6 sites on a 30km length survey line that crosses the basin with a west-southwest to east-northeast direction. Figure 1 shows the investigation sites on the dominant period map obtained through the three component microtremor measurements and strong ground motion observations presented by Lermo and Chavez-Garcia (1994). The microtremor array measurements used 25 to 650m equilateral triangular arrays. Table 1 summarizes the maximum size of array at each site and the latitude and longitude of center of the arrays. Figure 2 shows examples of the array configurations.

Table 1. Maximum array size and location of site.

Site name	Size	Latitude	Longitude
	(length of a side)	(degrees)	(degrees)
Texcoco No.7	50m	19.47883	98.99748
Texcoco No.8	500m	19.55757	98.99228
Texcoco TXC	200m	19.49203	98.97625
Aragon	650m	19.46228	99.06756
Almeda	100m	19.43585	99.14497
Chapultepec	330m	19.42294	99.18256

3 DATA ACQUISITION

Data acquisition was carried out during the daytime in December 2008 and December 2009. Microtremor measurement systems (JU210) made by Hakusan Corporation and data loggers (GPL-6A3P) made by Mitsutoyo Corporation were mainly used for data acquisition. Both systems use accelerometers for the sensors. In order to verify applicability of the accelerometers, servo-type velocity meters made by Katsujima Corporation (SD-110) and Tokyo Sokushin Corporation (VSE11F, VSE12F) were also used in the three-component microtremor measurements and H/V spectra obtained through the accelerometers and the velocity meters were compared. Thirty minutes to one-hour of microtremors were recorded for each three component measurement or array measurement.

Figure 3 shows the comparison of H/V spectra at the Texcoco No.7 site. Six systems, two Hakusan accelerometrs, two Mitsutoyo accelerometers, one set of Katsujima velocity meters and one set of Tokyo Sokushin velocity meters, were compared. H/V

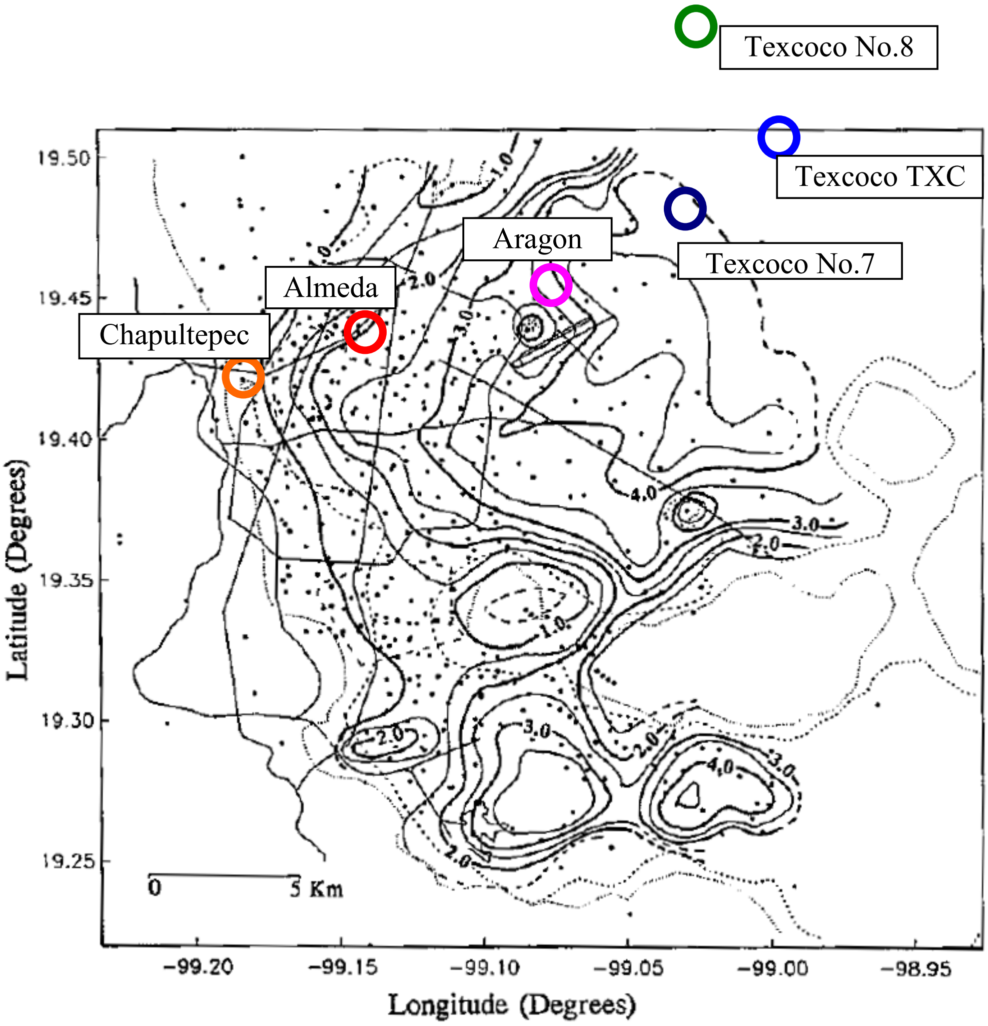


Figure 1. Investigation sites on a map of dominant period (modified from Lermo and Chavez-Garcia[2]). Contour lines in the map shows dominant period obtained through the three component microtremor measurements and strong ground motion observations.

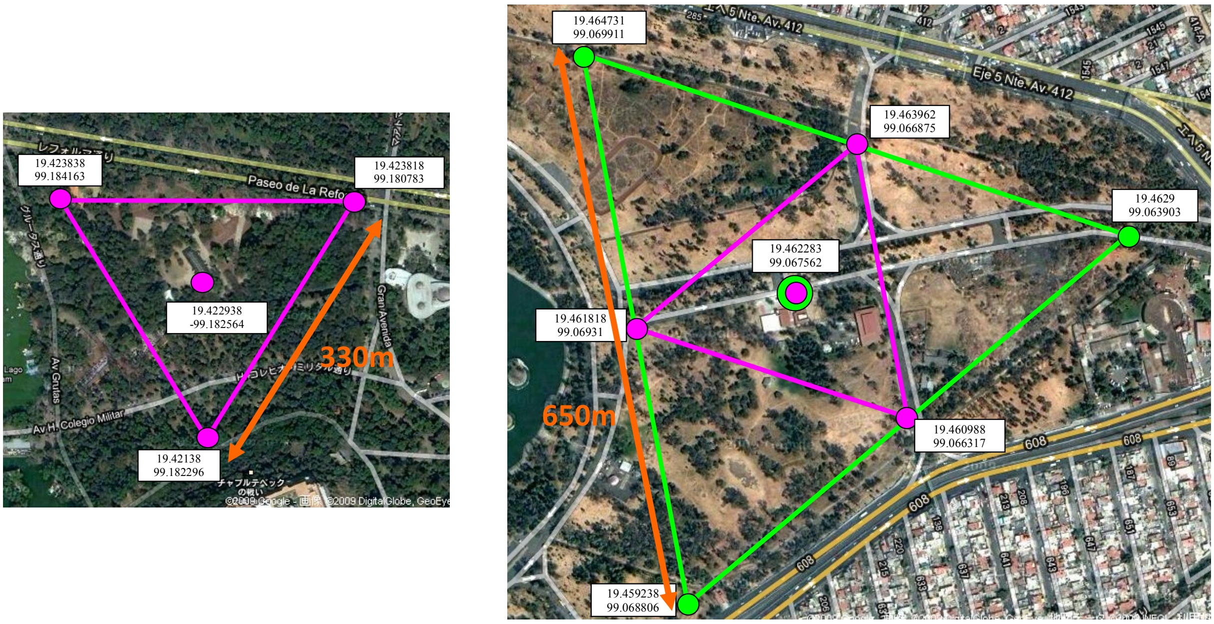


Figure 2. Example of array configuration (left : Chapultepec, right : Aragon)

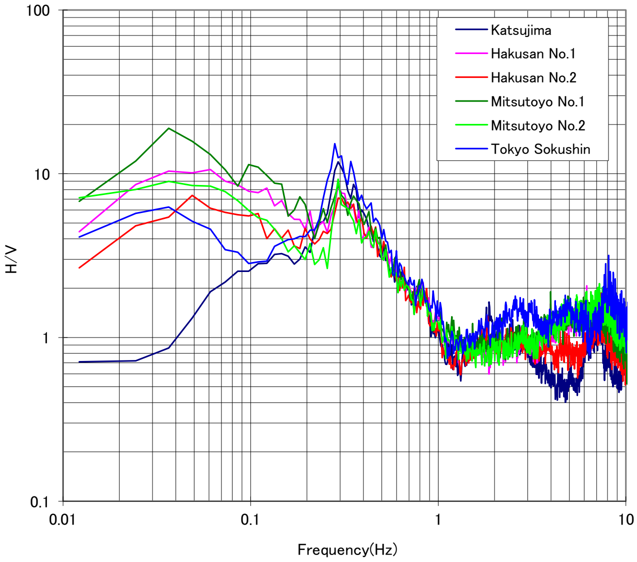


Figure 3. Comparison of H/V spectra at Texcoco No.7.

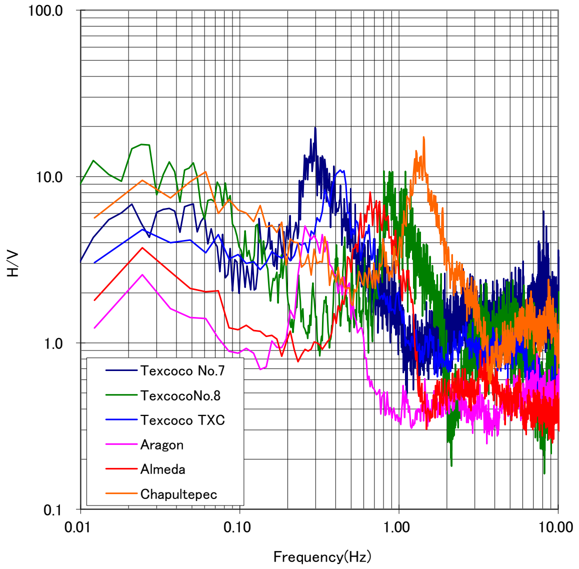


Figure 4. Comparison of H/V spectra.

spectra above the frequency of 0.2Hz are almost identical and a clear peak at the frequency of 0.3Hz is obtained by all systems. At the frequency below 0.2Hz, there is large difference in H/V spectra and no clear peak is observed. Based on this comparison of the accelerometers and the velocity meters, we will discuss H/V spectra and dispersion curves in the frequency range higher than 0.2 Hz in following sections.

4 ANALYSIS RESULTS

4.1 *H/V spectra*

Figure 4 shows H/V spectra obtained through three-component microtremor measurements performed at six sites throughout the basin (Figure 1). At the Aragon, Texcoco No.7 and Texcoco TXC sites located in the middle of the basin, the peak frequency of H/V spectra are 0.25 to 0.3Hz. In contrast, at the Texcoco No. 8, Almeda and Chapultepec sites located at the edges of the basin, the peak frequency is about 1Hz. We can see that these variations in peak frequency are due to basin structure. Furthermore, when we compare the peak frequencies from the Chapultepec, Almeda and Aragon sites, we see that they decrease from west to east, toward the center of the basin. Obtained peak frequencies of H/V spectra agree very well with the dominant period frequency map (Figure 1) presented by Lermo and Chavez-Garcia (1994).

4.2 *Dispersion curves*

Figure 5 shows dispersion curves obtained at 6 sites shown in Figure 1. At the Aragon and Texcoco No.7 sites that are located in the middle of basin, phase velocity is extremely low, lower than 100 m/s at a frequency of 1Hz. In contrast, phase velocity is much higher, as high as 100 to 500m/s at a frequency of 2Hz at Texcoco No.8 and Chapultepec sites that are located at the edge of the basin. It must be noted that the sites where the peak frequency of H/V spectra is higher, the phase velocity of the dispersion curve is also higher. The H/V spectra and the dispersion curves agree very well.

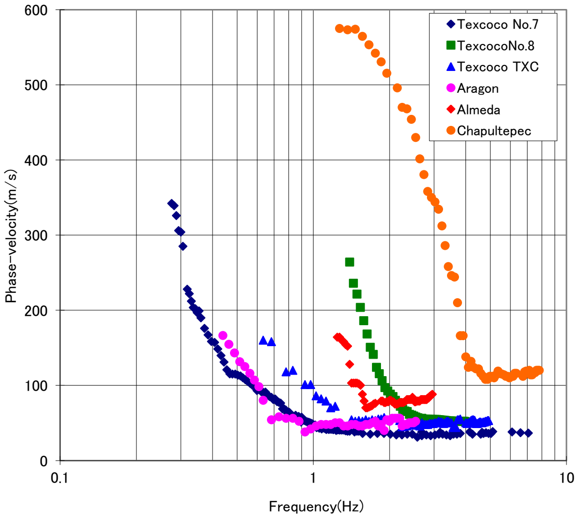


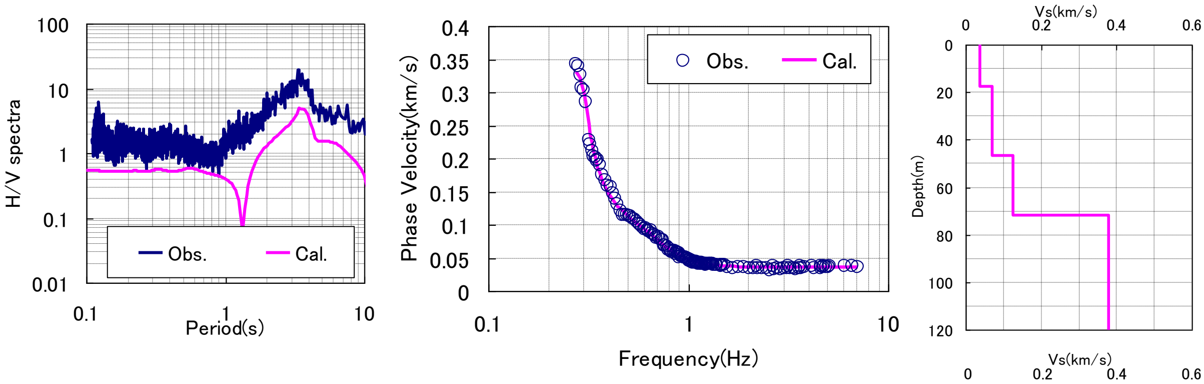
Figure 5. Comparison of dispersion curves.

4.3 *S-wave velocity model*

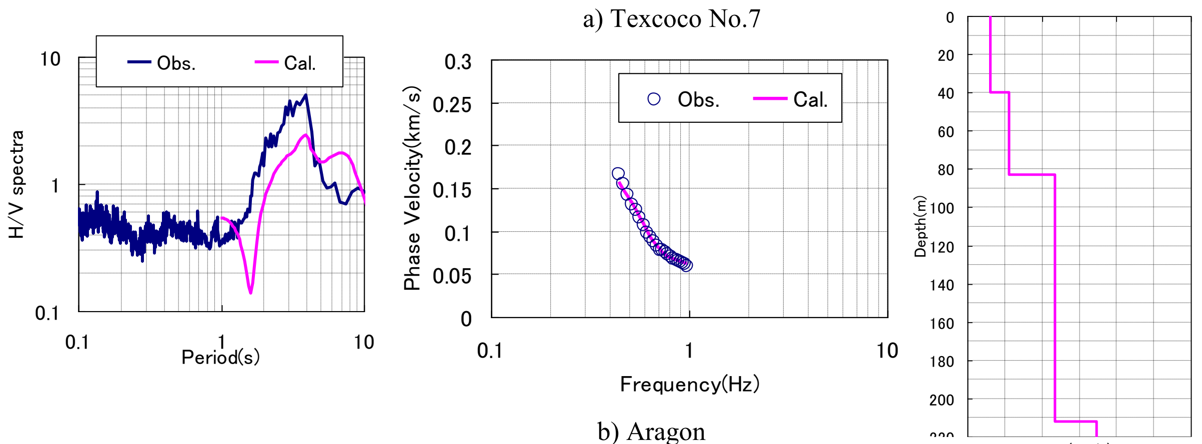
A joint inversion (Suzuki and Yamanaka, 2010) was applied to the observed H/V spectra and dispersion curves, and S-wave velocity models were analyzed for six sites. In the inversion, phase velocities of the dispersion curves and peak frequencies of the H/V spectra were used as the observation data. Unknown parameters were layer thickness and S-wave velocity. A Genetic algorithm (Yamanaka and Ishida, 1995) was used for optimization. Initial models were created by a simple wavelength transformation in which wavelength calculated from phase velocity and frequency is divided by three and plotted at depth. Theoretical H/V spectra and phase velocities are generated by calculating the weighted average of the fundamental mode and higher modes (up to the 4th mode) based on medium response.

Figure 6 shows the H/V spectra, dispersion curves and S-wave velocity models for Texcoco No.7, Aragon, Almeda and Chapultepec. Observed and theoretical data for H/V spectra and dispersion curves are compared. We see that the theoretical phase velocities almost agree with observed data at both sites. In the H/V spectra, theoretical and observed peak frequencies are almost identical. The absolute value of theoretical and observed H/V spectra has a slight difference at both sites.

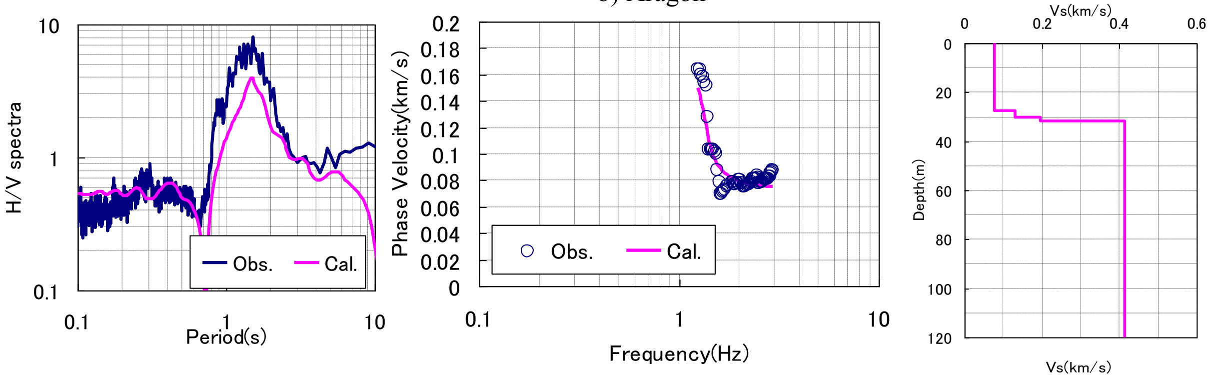
Figure 7 compares the peak frequencies and the S-wave velocity models at four sites along the survey line. At the Chapultepec site located at the edge of basin, S-wave velocity is about 100m/s just beneath



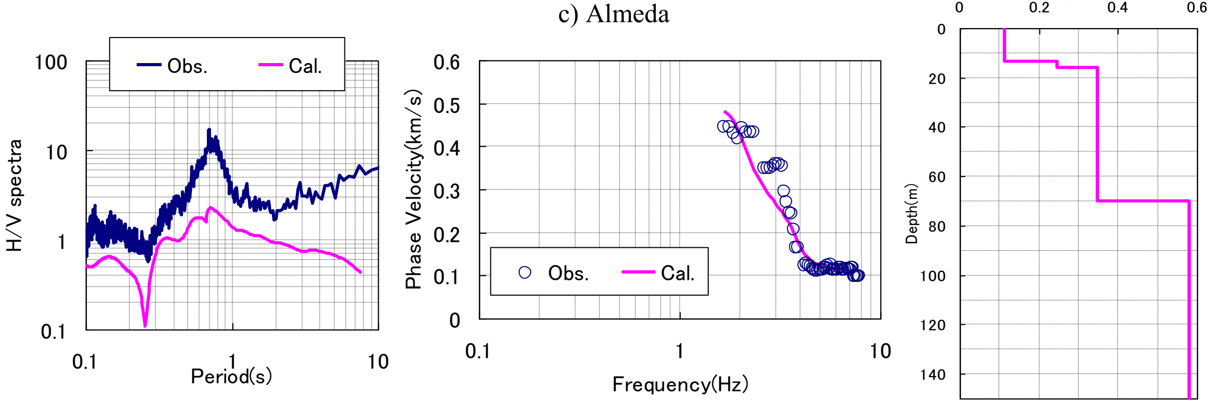
a) Texcoco No.7



b) Aragon



c) Almeda



d) Chapultepec

Figure 6. Comparison of H/V spectra (left), dispersion curves (middle) and S-wave velocity models (right). “Obs.” means observed data and “Cal.” Means theoretical data.

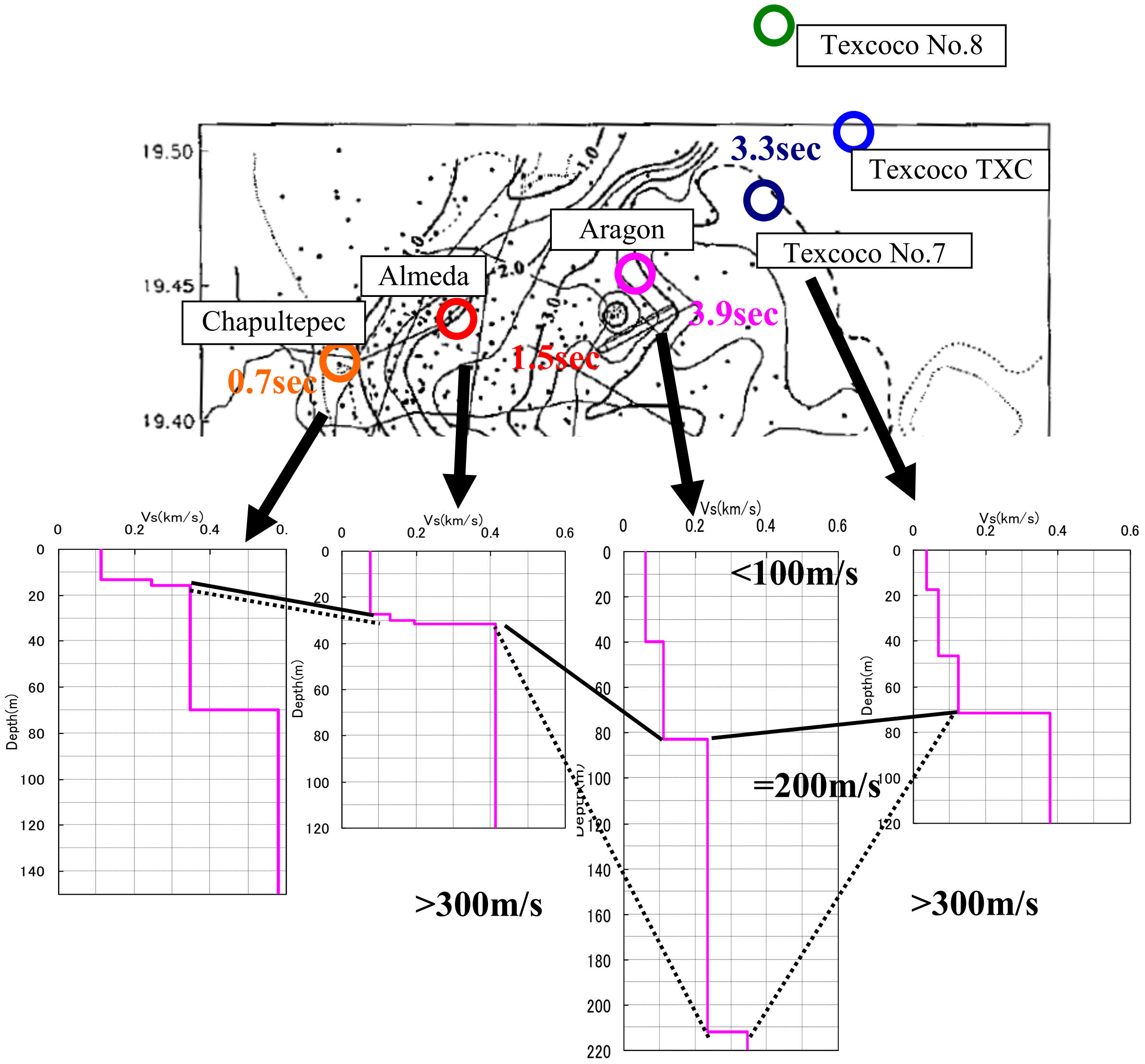


Figure 7. Comparison of S-wave velocity models and peak frequencies of H/V spectra.

the surface and about 300m/s at a depth of 10m. At the Almeda site located in middle of downtown, S-wave velocity is also about 100m/s just beneath the surface. Thickness of this low-velocity layer, however, is about 30m and much thicker than Chapultepec site. S-wave velocity just beneath the surface is extremely low (50m/s) at the Aragon and Texcoco No.7 sites that are located in the middle of the basin. Thickness of this low-velocity layer is about 40m at Aragon and 20m at Texcoco No.7. The top of the high-velocity layer in which, S-wave velocity is about 300m/s is at the depth of 200m at Aragon and 70m at Texcoco No.7. Depth of the high-velocity layer is much deeper at these sites compared with the Chapultepec and Almeda sites. At Aragon and Texcoco No.7 sites, S-wave velocity is lower than 150m/s down to 70m depth. These two sites can be characterized by extremely low S-wave velocity is at great depth. In the middle of basin, the peak frequency of H/V spectra is 0.25 to 0.3Hz. This seems reasonable due to the low-velocity layer shallower than the depth of 100m.

When we compare S-wave velocity models from Chapultepec, Almeda and Aragon, we see that S-wave velocity just beneath the surface decreases from west to east. Thickness of the low-velocity layer (< 100m/s) increases and the top of high-velocity layer (>300m/s) deepens from west to east, toward the center of basin respectively.

5 COMPARISON WITH OTHER PLAINS

The H/V spectra and the dispersion curves obtained from this study will be compared with those at other plains.

Figure 8 shows the comparison of the H/V spectra, the dispersion curves and the S-wave velocity models obtained at Soka (Hayashi et al., 2006) and Tsukuba, Japan and obtained at Aragon in the middle of the Mexico basin. Both Soka and Tsukuba are places in the Kanto Plain. Soka is a typical alluvial plain and Tsukuba is typical Diluvium terrace. There are two clear peaks, at periods of 7sec and 1sec, in the H/V spectrum at Soka site. It seems that the longer peak (7sec) is due to deep bedrock (seismic bedrock) at a depth of several kilometers and shorter peak (1sec) is due to shallow bedrock (bedrock between alluvium and diluvium) at a depth of about

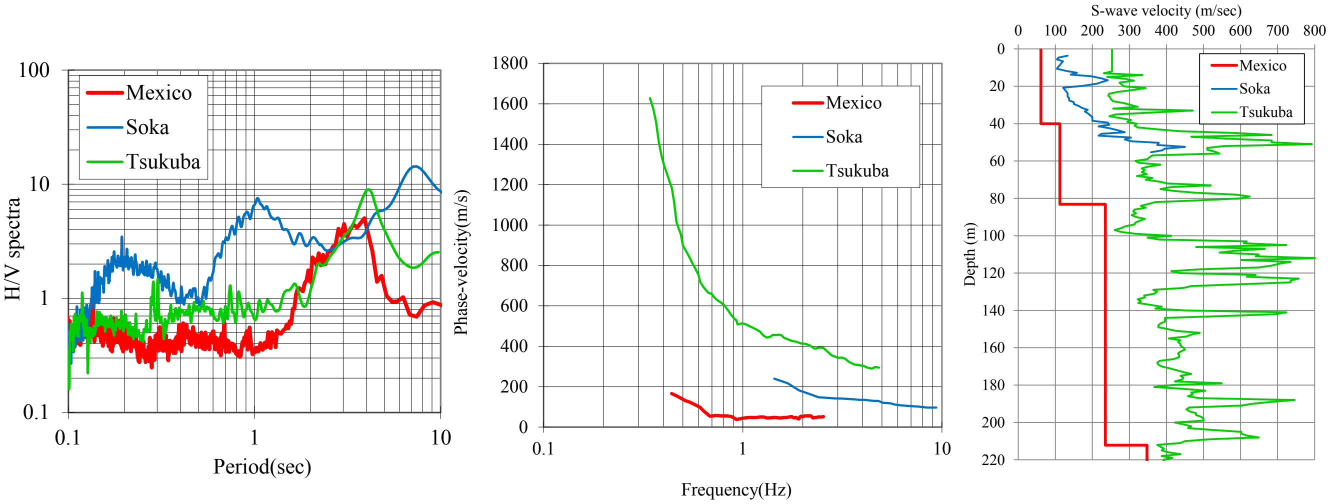


Figure 8. Comparison of H/V spectra (left), dispersion curves (middle) and S-wave velocity models (right) obtained at Soka and Tsukuba Japan and Aragon Mexico. (For data acquisition, Hakusan and Mitsutoyo's accelerometers were used in Mexico and Yokyo Sokushin's velocity meters were used in Japan).

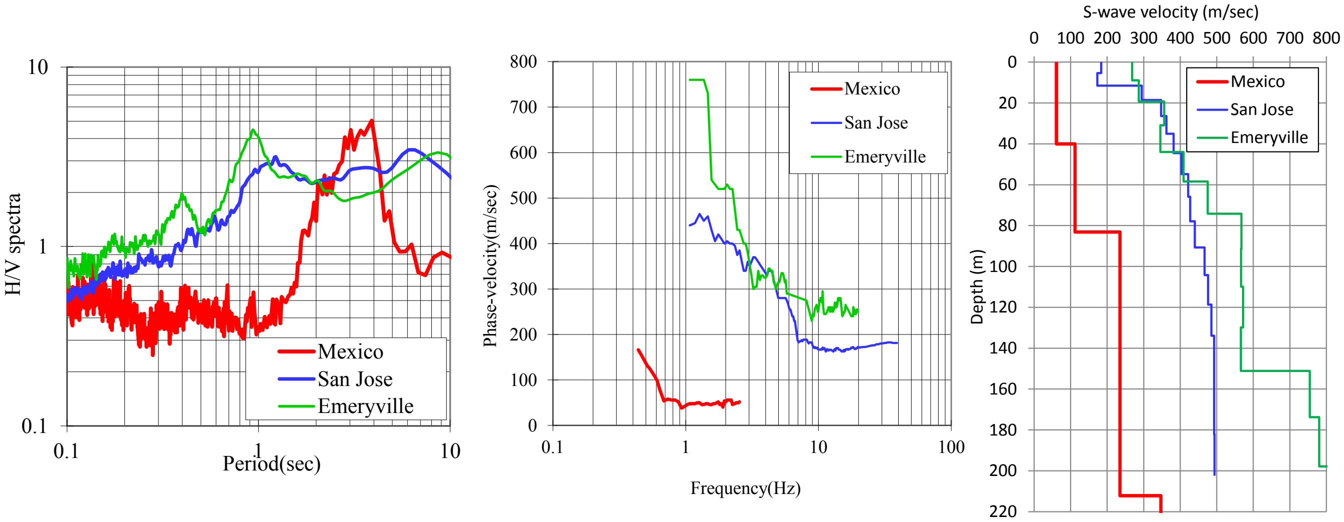


Figure 9. Comparison of H/V spectra (left), dispersion curves (middle) and S-wave velocity models (right) obtained at San Jose and Emeryville Tsukuba Japan and Aragon Mexico. (For data acquisition, Hakusan and Mitsutoyo's accelerometers were used in Mexico and OYO's accelerometers (McSEIS MTNeo) were used in United States).

50m. There is one clear peak, at periods of 4sec in the H/V spectrum at Tsukuba site. The peak is due to deep bedrock at a depth of about 650m.

Figure 9 shows similar comparison at San Jose and Emeryville, CA, United States and Aragon. There are two peaks, one clear peak at periods of 1sec and another vague peak at periods longer than 5 sec, in the H/V spectrum at both Sun Jose and Emeryville sites. It seems that the longer peak (longer than 5sec) is due to deep bedrock at a depth of several kilometers and shorter peak (1sec) is due to shallow bedrock at a depth of 50 to 200m.

In recent years, long-period strong ground motion (periods of several seconds) mainly due to deep bedrock structure down to depths of several kilometers, has provoked a great deal of controversy over Japanese large plains, such as Kanto, Nobi and Osaka. It seems that the strong ground motion with periods of 1 to 4 seconds (frequency of 0.25 to 1Hz) dominates in the Mexico basin as shown in Figure 1. Unlike Japanese or American plains, the long-period ground motion in the Mexico basin is mainly due to the low-velocity layer shallower than a depth of 100m as shown in Figures 8 and 9. Seo (1986) has pointed out that that the long-period strong ground motion in the Mexico basin is mainly due to near-surface velocity structure unlike Japan. We can say that the investigation result presented in this paper has confirmed Seo's assertions.

6 CONCLUSIONS

We have performed the three-component microtremor measurements and microtremor array measurements in the Mexico basin and estimated the S-wave velocity models to a depth of 200m. S-wave velocity in the middle of the Mexico basin is lower than 150m/s to a depth of 70m and much lower than typical Japanese and American plains. Peak frequencies of the H/V spectra in Mexico City vary from 0.25 to 1Hz and it seems that these peak frequencies are mainly due to the low-velocity layer shallower than a depth of 100m.

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