Copyright © 1996 Elsevier Science Ltd
Paper No. 1764. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

GROUND-MOTION CHARACTERISTICS IN SANTIAGO, CHILE, OBTAINED BY MICTOTREMOR OBSERVATIONS

T. TOSHINAWA*, M. MATSUOKA* and Y. YAMAZAKI**

* Department of Built Environment, Tokyo Institute of Technology
4259 Nagatsuta, Midori-ku, Yokohama 226, JAPAN

** Engineering Geophysics and Research Institute, Oyo Corporation
2-2-19, Daitakubo, Urawa 336, JAPAN

ABSTRACT

Microtremor measurements were carried out in Santiago, Chile, in order to investigate ground-motion characteristics in the city. Horizontal to vertical spectral ratios of microtremors proposed by Nakamura (1989) were obtained for 31 observations sites including 5 strong-motion sites. The horizontal to vertical spectral ratios were compared to spectral ratios obtained from strong motions and detected ground-motion characteristics at the strong-motion sites. Predominant periods of the spectral ratio in the period range longer than 1 sec was related to the thickness of Pleistocene deposits while spectral characteristics of the ratio in the period range shorter than 1 sec were related to surface soils such as artificial fill and stiff pumice.

KEYWORDS

Microtremor observations; ground-motion characteristics; local site effects; predominant periods

INTRODUCTION

Santiago is the capital of Chile, which has suffered strong ground shakings such as the 1960 and 1985 events. Since the city is situated on a basin constituted by the Holocene and Pleistocene deposits, local site effect is one of the most important factors to predict ground shakings during earthquakes. To evaluate local site effect, a strong-motion accelerograph array (SMASCH array) was deployed since 1989 and site effects of the strong-motion sites were evaluated from observed strong motions (Midorikawa *et al.*, 1991).

In this study, microtremor observations were carried out in the city in order to interpolate the site effects evaluated from the strong motions. Horizontal to vertical spectral ratio of microtremors proposed by Nakamura (1989) was employed here. The spectral characteristics of the horizontal to vertical spectral ratios at the strong-motion sites were firstly compared to spectral ratios obtained from strong motions, following which spot microtremor observations were carried out. The characteristics of the horizontal to vertical spectral ratios were investigated and compared to subsurface soils and the thickness of the Pleistocene deposits.

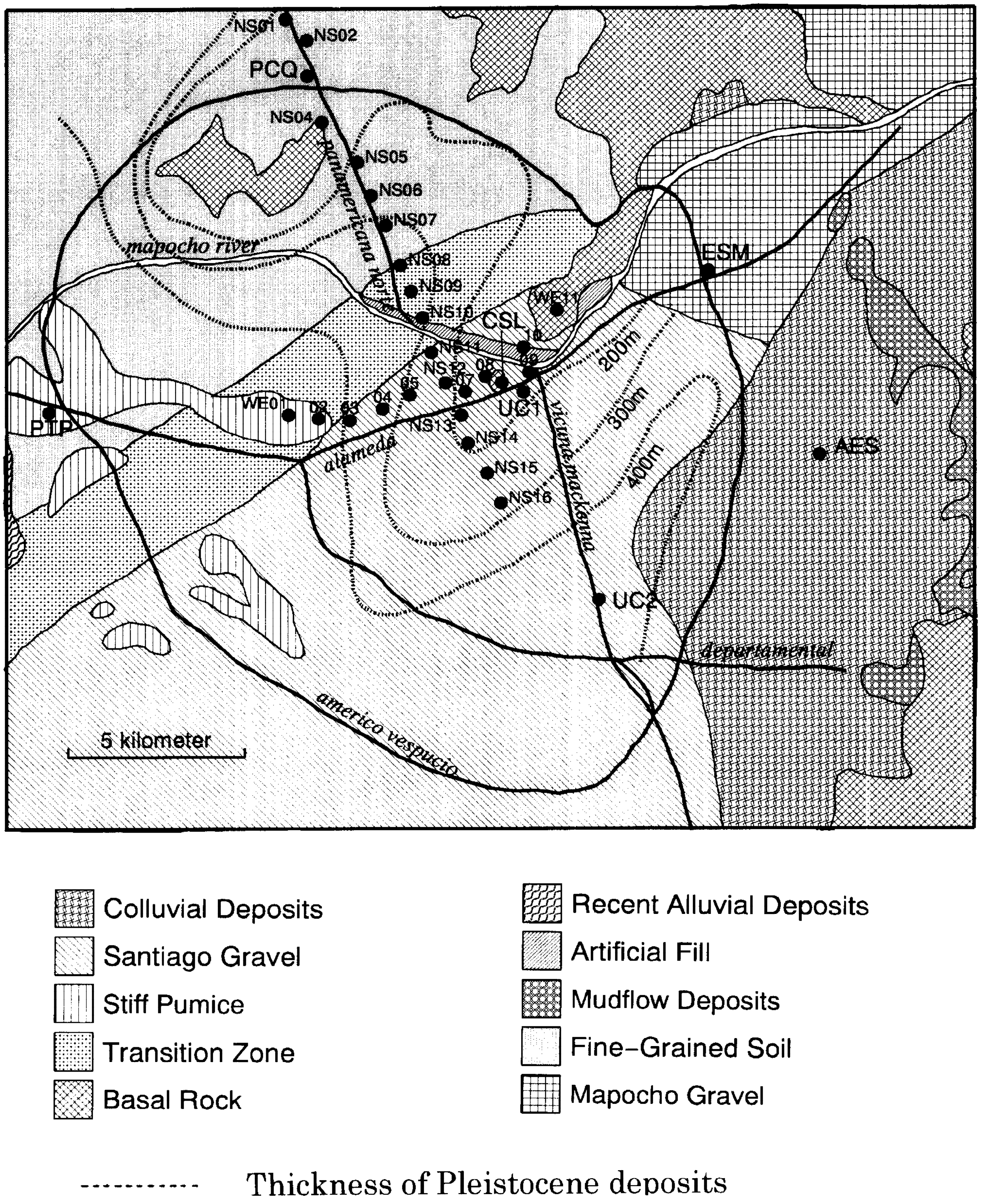


Fig. 1 Geological map of Santiago (after Valenzuela, 1978) with strong-motion and microtremor observation sites.

REGIONAL GEOLOGY

Fig.1 shows geological map of the city of Santiago (Valenzuela, 1978). The city is located on a basin surrounded by the Andes and the coastal mountains. Most of the sediments in the city came from the Andes mountains by streams. Because of the difference of the Holocene deposit formations, the city can be divided into several geological parts as shown in the figure. Gravel was mainly deposited in the central and southern parts of the city (Santiago gravel) while fine-grained soil was formed in the northwestern part of the city. A transition zone is found between the gravel and fine-grained soil. Colluvial deposits covers the ground surface in the eastern part of the city while isolated basal rocks are found in the center of the city and in the fine-grained soil area. Stiff pumice was partly deposited in the western part of the city. Artificial fill covered the riverside of the Mapocho river in the central part of the city. The depth of the Pleistocene deposits indicated by broken lines in the figure has the depth of 400 m in the western part of the city gradually becoming shallower toward the outcrops.

MICROTREMORS AT STRONG-MOTION SITES

Ground-Motion Characteristics at Strong-motion Sites

The SMASCH array consists of seven observation sites which are located on different soil conditions as shown in Fig.1. Fig.2 shows average spectral ratios at the strong-motion sites with respect to a rock site (CSL), the ratios of which were obtained from several strong motions observed from July 1989 to December 1990 (Cruz *et al.*, 1993). PCQ, which is situated on the fine-grained soil, has spectral peaks between 0.1 and 0.2 sec while the gravel site, UC1, has a short-period peak at about 0.07 sec. AES (on colluvial deposits), PCQ (on fine-grained soil), and PTP (on stiff pumice) have high spectral amplitudes in the period range longer than 0.7 sec. Fig.3 shows soil and shear-wave velocity profiles at PCQ, PTP, UC1 and UC2 (Midorikawa *et al.*, 1991). UC1 sits on a 3-m thick artificial fill with shear-wave velocity 130 m/s overlying stiff gravel with shear-wave velocity 650 m/s, the profile of which probably causes site response at about 0.07 sec as was observed in Fig.2. PTP sits on stiff pumice which has shear-wave velocity of 300 m/s near the ground surface. The velocity contrast is not clear at this site. PCQ has silt-sand, silt-clay, and gravel with shear-wave velocity less than 200 m/s over the 5-m depth, the profile of which might cause site amplification at about 0.1 sec.

Microtremor Observations at Strong-motions Sites

In this study microtremor measurements were firstly made at the strong-motion accelerograph sites in order to investigate the applicability of the technique using microtremors in this city. At each site, three sets of 40-sec long microtremors in velocity were collected for three components at a sampling rate of 100 Hz. Three sets of 20-sec long samplings with less contamination of traffic noise were carefully selected for spectral analyses. Fourier amplitude for each sampling was smoothed with a 0.5 Hz Parzen window, following which the horizontal Fourier amplitudes were divided by the vertical ones. The spectral ratios were finally averaged and to be called 'H/V spectral ratios'. Although H/V spectral ratios were obtained for two horizontal components, H/V spectral ratios for EW components were used for the evaluation of ground-motion characteristics because some records in NS components have long-period noises induced by electrical malfunction.

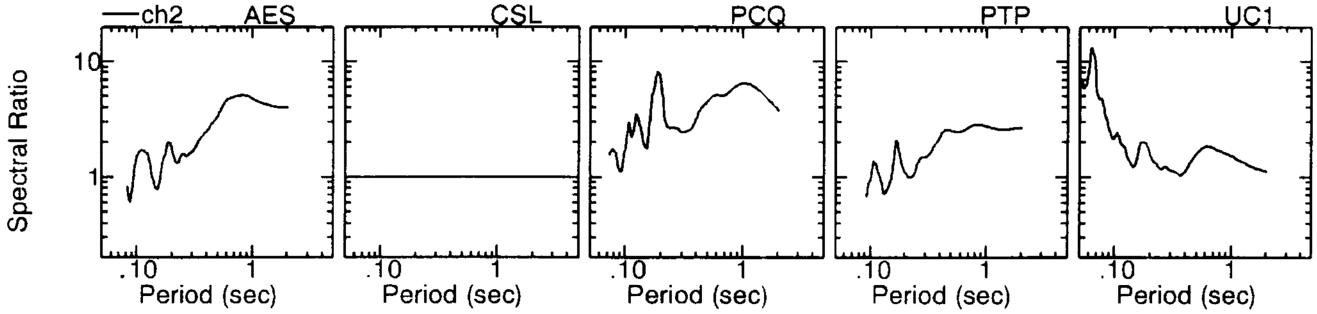


Fig. 2 Average spectral ratios of motions at soil sites UC1, UC2, PTP, AES, and PCQ with respect to rock site CSL (after Cruz *et al.*, 1993).

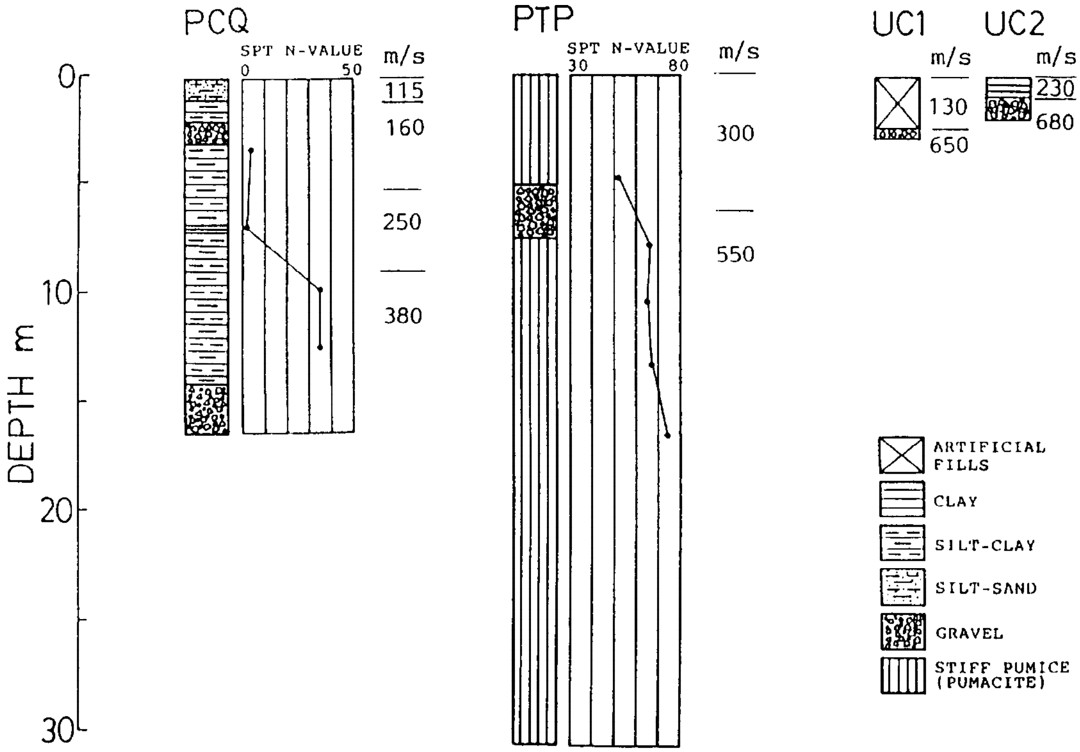


Fig. 3 Soil and shear-wave velocity profiles at UC1, UC2, PTP, and PCQ of the SMASCH array (after Midorikawa *et al.*, 1991)

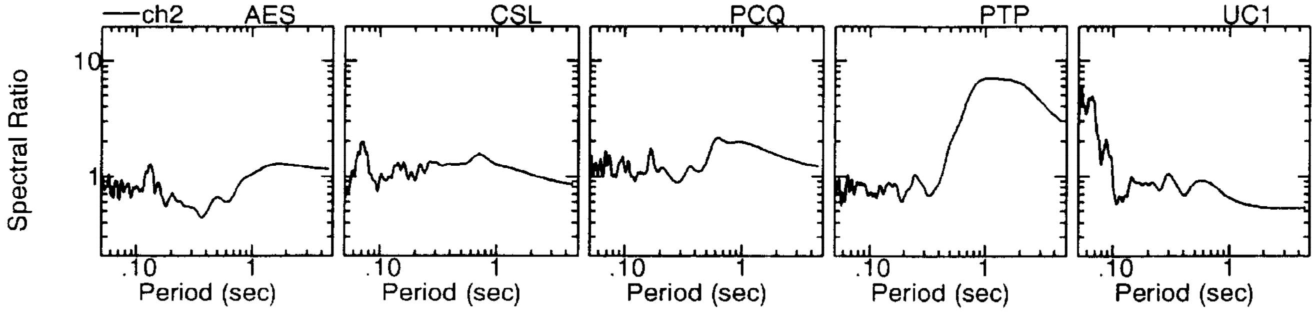


Fig.4 Horizontal to vertical spectral ratios of microtremors at strong-motion sites.

Comparison of Spectral Ratios

Fig.4 shows H/V spectral ratios at the five strong-motion sites. As the characteristics of H/V spectral ratio is said to be related to ground-motion characteristics (Lermo and Chávez-García ,1994), the H/V spectral ratios at the strong-motion sites were compared to the spectral ratios in Fig.2.

<AES> The high spectral amplitude in the period range longer than 0.7 sec found in Fig.2 is not observed in the H/V spectral ratio. Predominant periods about 0.1 sec are consistent although these peaks are not sharp.

<CSL> The H/V spectral ratio at the reference site has spectral amplitude less than 2 showing that this site has less ground-motion characteristics.

<PCQ> Both the spectral ratios in Figs.2 and 4 have spectral peaks at about 0.2 sec although the spectral peak amplitude of the H/V spectral ratio is small.

<PTP> Both the spectral ratios in Figs.2 and 4 have higher amplitude in the period range from 0.4 to 3 sec in comparison to the other period range although the spectral amplitudes are different.

<UC1> The marked spectral peak amplitudes at about 0.07 sec found in Fig.2 is also observed in the H/V spectral ratio. As was discussed before, these peaks are due to the artificial fill near the ground surface.

In this city, predominant periods of the horizontal to vertical spectral ratios were correlated with those of the spectral ratios obtained from strong motions although spectral peak amplitude were not necessarily consistent.

SPOT MICROTREMOR OBSERVATIONS

Next, spot microtremor observations were carried out in the city, the points of which are shown by dots in Fig.1. Two observation lines were selected, one was called 'N-S line' and the other was called 'W-E line'. The N-S line was deployed from the fine-grained soil area to the Santiago gravel area including the isolated basal rock and the transition areas. The W-E line was deployed from the stiff pumice area to the basal rock area including the Santiago gravel and the isolated basal rock areas. H/V spectra were obtained in the same way as the observations at the strong-motion sites. Here, predominant period and its spectral peak amplitude are to be called 'Tp' and 'Ap', respectively. As most of the H/V spectra have two or three spectral peaks, Tp and Ap were determined for three period regions ; (a) Tp $\geqq$ 1 sec, (b) 0.4 $\leqq$ Tp $\leqq$ 1 sec, and (c) Tp $\leqq$ 0.4 sec. In Figs. 5, 6, 7, 8, 10, and 11, Tp values are indicated by ●, ■, and ▲ while Ap values are indicated by ○, □, and △. The thickness of the Pleistocene deposits are also shown in Figs. 5 and 6. From these figure, the following findings can be stated:

(1) Tp values in the period range (a) are correlated with the thickness of the Pleistocene deposits. By employing the Tp values and the thickness for the quarter wavelength law, average shear-wave velocity of the deposits can be estimated to be 600m/s which is consistent with the shear-wave velocity of the gravel underlying the surface soil of UC1 and UC2 in Fig.3 (See Figs. 5 & 6).

(2) Ap values at WE09 and WE10 in the period range (b) exceed 10. According to the geological map in Fig. 1, the points are located on or around the artificial fill along the Mapocho river (See Fig. 7).

(3) Tp values in the period range (b) for NS08-NS12 are longer than those for the other points. According to the geological map in Fig. 1 and geological cross section in Fig. 9, these points are located on the transition area. As the surface soil in the transition area have a thickness of about 30m, the strata might affect the period range (b) (See Fig. 8).

(4) Several observation sites have the spectral peaks in the period range (c). These points are located on the stiff pumice in the W-E line and on the fine grained soil in the N-S line (See Figs. 10 & 11).

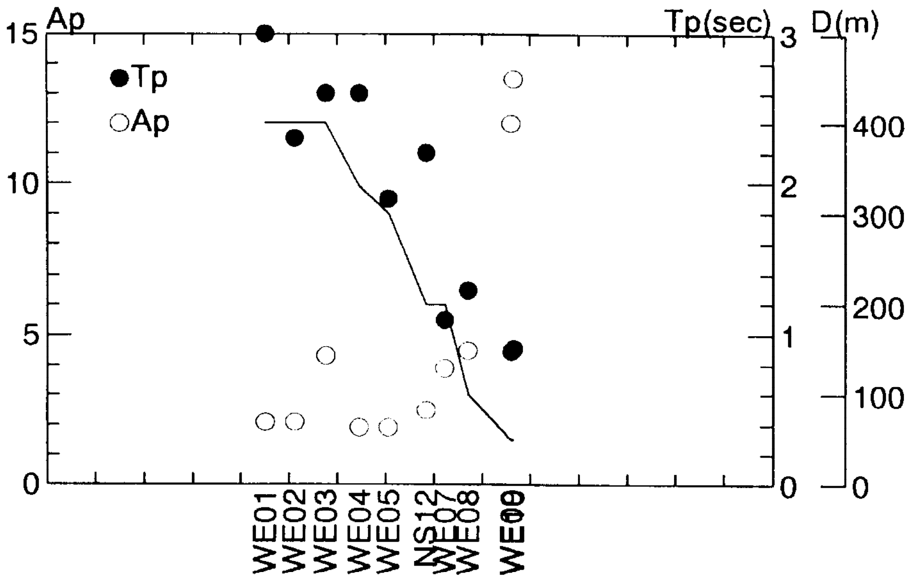


Fig.5
Predominant periods and spectral peak amplitudes along the W-E line in the period range longer than 1 sec.

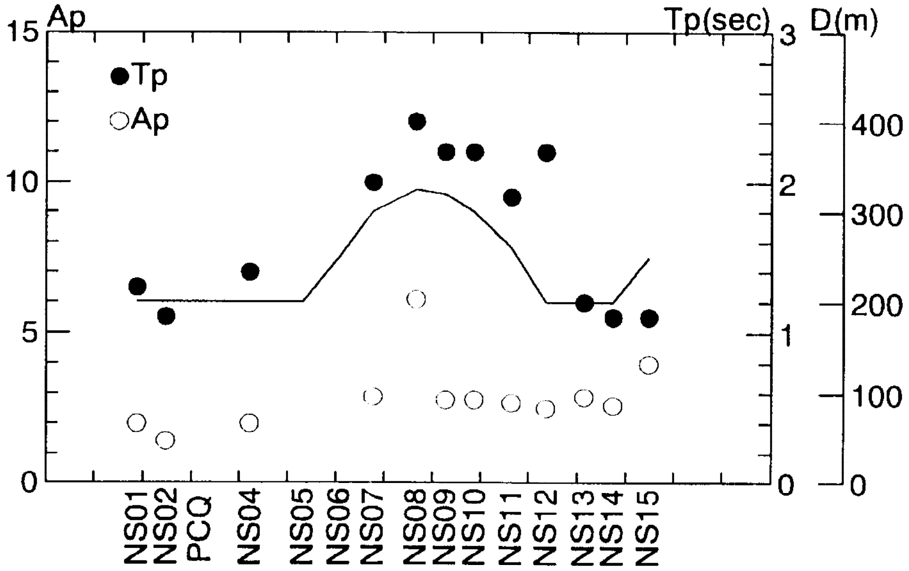


Fig.6
Predominant periods and spectral peak amplitudes along the N-S line in the period range longer than 1 sec.

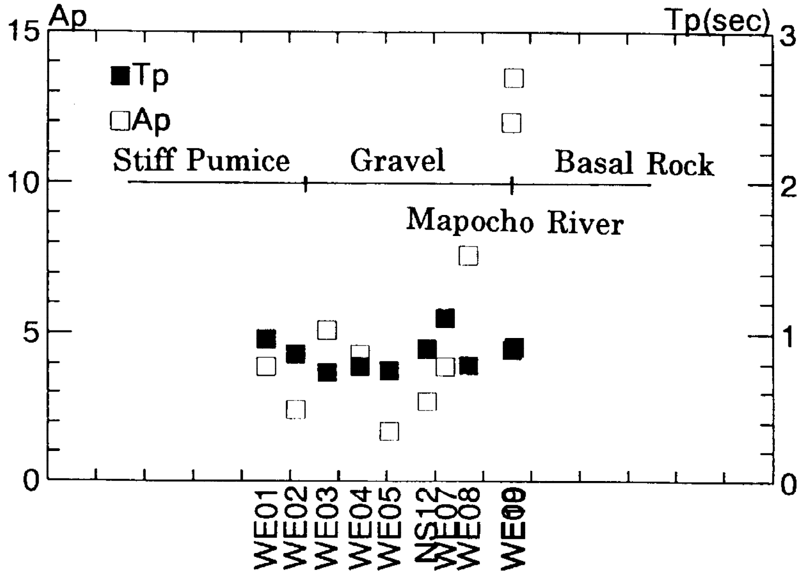


Fig.7
Predominant periods and spectral peak amplitudes along the W-E line in the period range from 0.4 to 1 sec.

Fig.8
Predominant periods and spectral peak amplitudes along the N-S line in the period range from 0.4 to 1 sec.

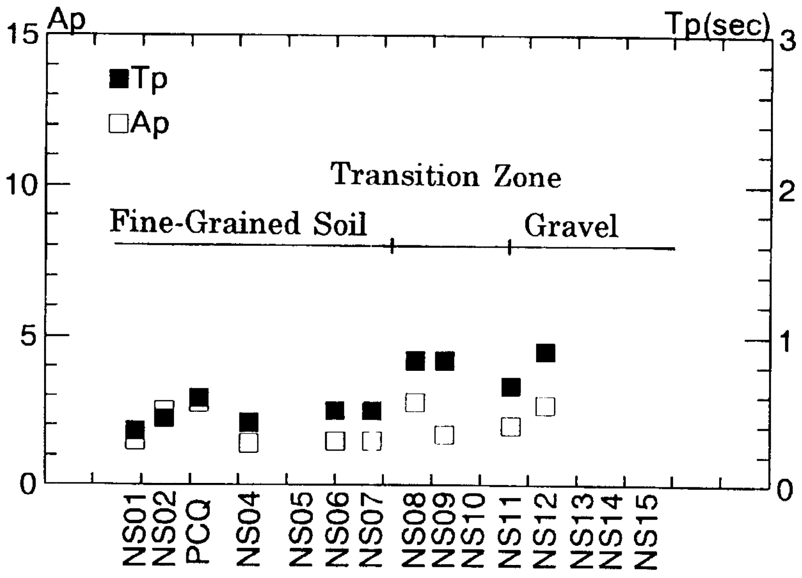


Fig.9
Geological cross section of the NS-line(after Valenzuela, 1978).

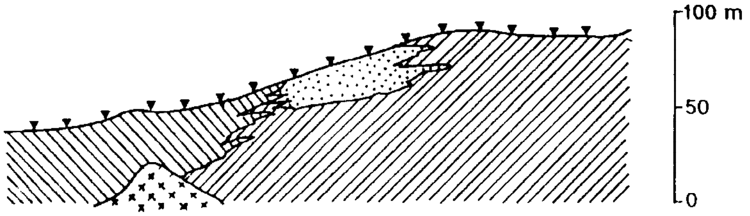
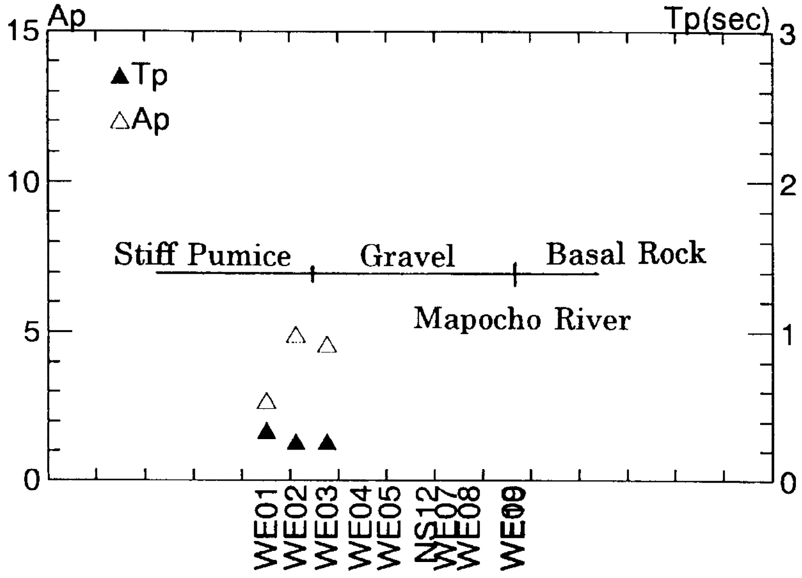


Fig.10
Predominant periods and spectral peak amplitudes along the W-E line in the period range shorter than 0.4 sec.



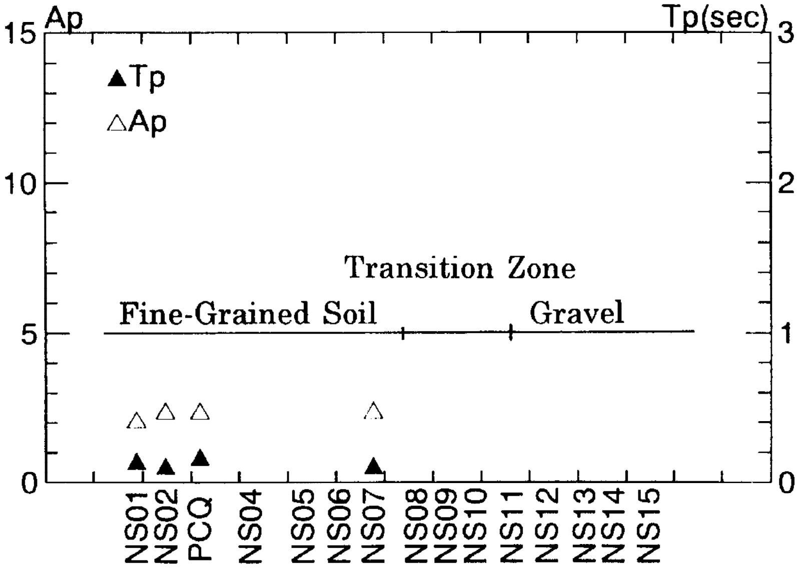


Fig.11
Predominant periods and spectral peak amplitudes along the N-S line in the period range shorter than 0.4 sec.

CONCLUSIONS

Microtremor observations were carried out in the city of Santiago. At strong-motion sites, predominant periods of the horizontal to vertical spectral ratios were correlated with those of the spectral ratios obtained from strong motions although spectral peak amplitude were not necessarily consistent. Tp values in the period range longer than 1 sec were correlated with the thickness of the Pleistocene deposits. Average shear-wave velocity of the deposits obtained from the Tp values and the thickness was consistent with the shear-wave velocity of the gravel underlying the surface soils. Spectral characteristics in the period range shorter than 1 sec were related to surface soils such as artificial fill, stiff pumice, and fine-grained soil.

ACKNOWLEDGMENT

The observations were assisted by Profs. Riddel and Cruz, Catolica University. This study was supported by a Grant-in-Aid for International Scientific Research of the Ministry of Education, Science and Culture, Japan.

REFERENCES

Cruz, E., R. Riddell, and S. Midorikawa (1993). A study of site amplification effects on ground motions in Santiago, Chile, *Tectonophysics*, **218**, 273-280.

Lermo J. and F. J. Chávez-García (1994). Are microtremors useful in site response evaluation ?, *Bull. Seism. Soc. Am.*, **84**, No.5, 1350-1364.

Midorikawa, S., R. Riddell, and E. Cruz (1991). Strong motion accelerograph array in Santiago, Chile, and preliminary evaluation of site effects, *Earthquake Eng. and Struct. Dyn.*, **80**, 403-407.

Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, *QR of RTRI*, **30**, No.1 25-33.

Valenzuela, G. B. (1978). Suelo de fundación del Gran Santiago, *Inst. Invest. Geol. Santiago, Chile*, **33**, 105.