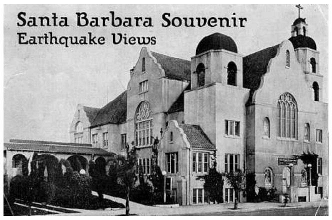

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MICROTREMOR EXPLORATION AT SEVEN STRONG MOTION STATIONS IN CHILE

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ABSTRACT

To evaluate site effect, we performed microtremor exploration at seven strong motion observation stations in Chile. Those stations are operated by department of civil engineering, the University of Chile. Ground motions of the 2010 Chile Maule region earthquake are recorded at those stations successfully. Three of seven stations are located in Santiago, and other four stations are more close to epicenter.

Array configuration of microtremor exploration is the right triangle. One three-component sensor is located in the center of the triangle, and three vertical component sensors are located at each apex of the triangle. Distance from the center to apex is 5 or 6 meter depending on a case. Additionally, we put one three-component sensor in the middle of a one side. Two hundred second length data are recorded with sampling frequency of 200Hz.

Phase velocity is estimated from both SPAC method and extended SPAC method. An average S-wave velocity for top 30 meter is estimated from phase velocity using an empirical relationship. As a result, the slowest Vs30 is 220 m/s obtained at CONSTITUION. In the inland area, Vs30s are about 500 m/s. In Santiago, Vs30s are ranged from 370 m/s to 690 m/s. The lowest Vs30 in Santiago is obtained at MAIPU where PGA is the largest among three stations. The highest Vs30 is obtained at MIRADOR where PGA is the smallest among three stations. So that we can point out that order of Vs30 is corresponding to order of PGA.

INTRODUCTION

The 2010 Chile Maule earthquake provides us a valuable opportunity to study an earthquake hazard induced by the huge size earthquake. To start such study, earthquake ground motion is a key issue. Fortunately, by the several organizations, including the department of civil engineering, University of Chile, earthquake ground motions are obtained. As ground motion contains a site effect, it should be considered to evaluate ground motion. However, so far, site effects of these sites are not revealed.

The author performed microtremor exploration at seven strong motion observation stations to study the site effects of these stations. Using phase velocities those are estimated from microtremor, evaluating an underground structure is normal microtremor exploration. As this scheme is a sort of inverse problem, it needs an appropriate initial model to get a good result. However, we do not have such information. Instead of normal exploration, an average S-wave velocity for top 30 meter (Vs30) is estimated from phase velocity using empirical relations. The author thinks that Vs30 is one index for understanding the site effect.

TARGET SITES

Seven stations are chosen as listed in Table 1. Those stations are operated by the department of civil engineering, the University of Chile. Three stations that code is MAIP, MIRA, and PENA are in Santiago. Other four stations are located closer to the epicenter. Figure 1 shows a map of station location, epicenter and horizontal projection of the fault estimated by Gavin (2010). Strong motion stations are located sparsely, and we had only for three days to go around. We could not go to the southern area.

Array observation needs several spaces, but at several stations, we do not find out a space in the same property of observation station. For such a case, we moved to adequate space where a site condition looks like similar to the strong motion station.

Table 1. Target Site

code	Strong motion observation station name	Exploration site	r (m)
MAIP	Santiago- C.R.S. MAIP	on the same property	5
MIRA	Santiago- Mirador Station Metro S. A.	at a distance 100 meter away	6
PENA	Santiago- Peñalolen	next to the property	6
HUAL	Hualañe	on the same property	6
CURI	Curico	on the same property	6
CONS	Constitution	at a distance 150 meter away	6
TALC	Talca	at a distance 250 meter away	5

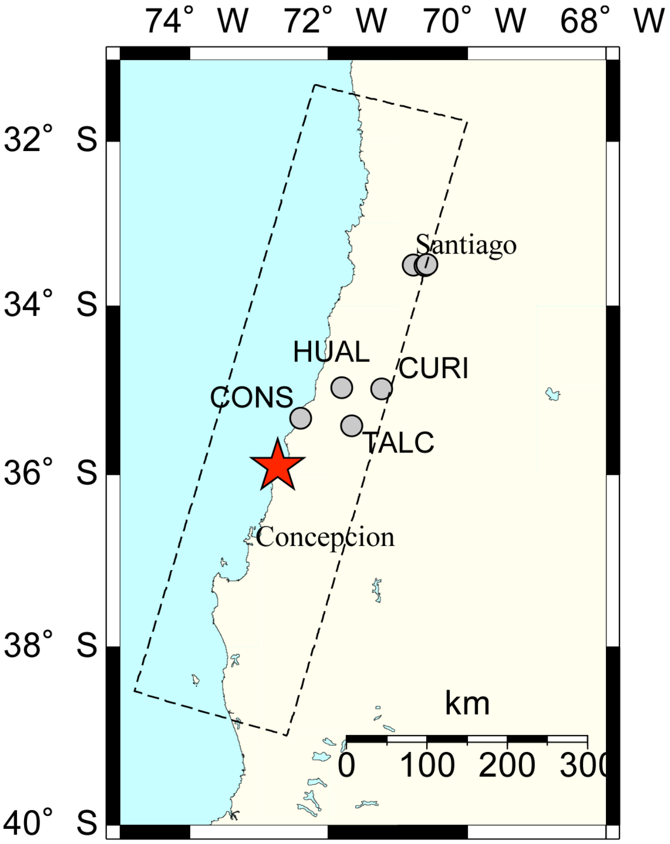

Figure 1. Map showing a target stations (solid circle), epicenter (star) and horizontal fault projection.

ESTIMATING AN AVERAGE S-WAVE VELOCITY

The Vs30 is estimated by phase velocity of Rayleigh wave. Konno *et al.* (2000) show a very close relationship between an average S-wave velocity for top layers and phase velocity of Rayleigh wave. Nagao *et al.* (2002) compile relationship between average S-wave velocities and phase velocities of Rayleigh wave. By their work, the Vs30 is approximated by phase velocity of Rayleigh wave with wavelength of 40 meter as equation (1).

$$Vs30=c(L=40) \qquad (1)$$

In eq. (1), c symbolizes phase velocity and it is a function of wavelength *L*.

Array observation

Array configuration is shown in Figure 2. At the center of the equilateral triangle, one sensor with three components is placed. At each apex, vertical component sensor is placed. At the middle of bottom side, one sensor is placed additionally. A distance from center to apex named *r* is ordinary six meter but for the MAIP and TALC, 5 meter is used. This *r* value is also listed in Table 1. At each site, two hundred second data was acquired three times with sampling frequency of 200Hz.

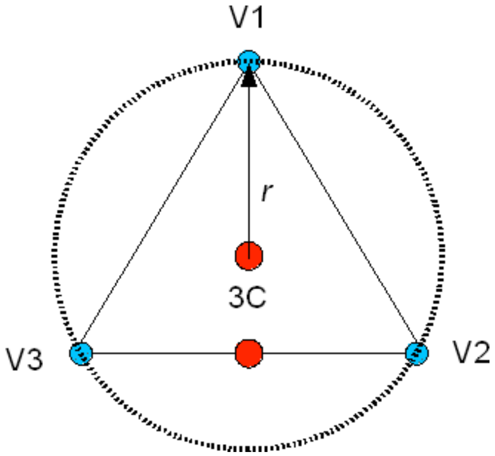

Figure 2. Array configuration.

Phase velocity

Phase velocity of Rayleigh wave is estimated by Spatial Correlation method (hereafter SPAC) proposed by Aki (1957). Figure 3 shows phase velocity with frequency for seven sites. There are two combinations to evaluate a spatial autocorrelation coefficient that is the center to apex and apex to apex. Those are marked in the figure independently. From the figure, two phase velocities yields from two coefficients are almost the same. The Vs30 is determined by the intersection of estimated phase velocity and 40 times frequency, empirically.

We also applied extended SPAC method (Okada, 2004). Phase velocity c is determined by minimizing the equation (2). To search adequate c in eq. (2), c is changed every 2 m/s. Estimated phase velocities for seven stations are displayed in Figure 7 with results of SPAC method. In this figure, the amount of residue of equation (2) is illustrated by gray color. Darker indicate the more proper result.

$$\sum_{j=1}^{N}\left\{coh\left(r_j,f_i\right)-J_0\left(\frac{2\pi f_i r_j}{c}\right)\right\}^2 \tag{2}$$

In this equation, r_j is distance of two stations, f_i is frequency, $coh(r_j, f_i)$ is coherency of two stations, $J_0()$ means 0-th order Bessel function, and N is number of sensor combination.

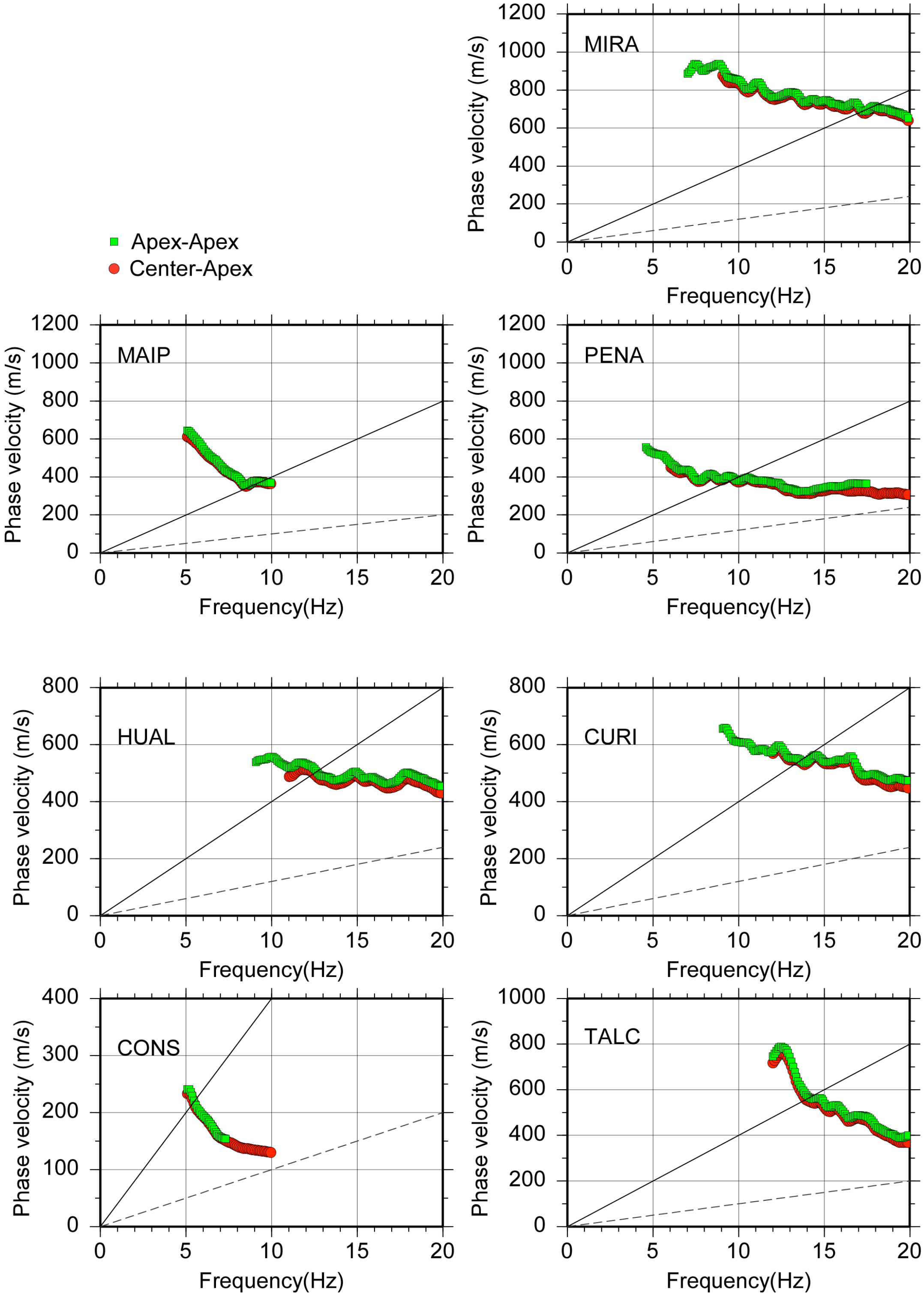

Figure3. Estimated phase velocity using SPAC method. Guide line to read a phase velocity with wavelength of 40 meters is also drawn by solid line. Dotted line indicates a lower limit velocity evaluated from spatial aliasing.

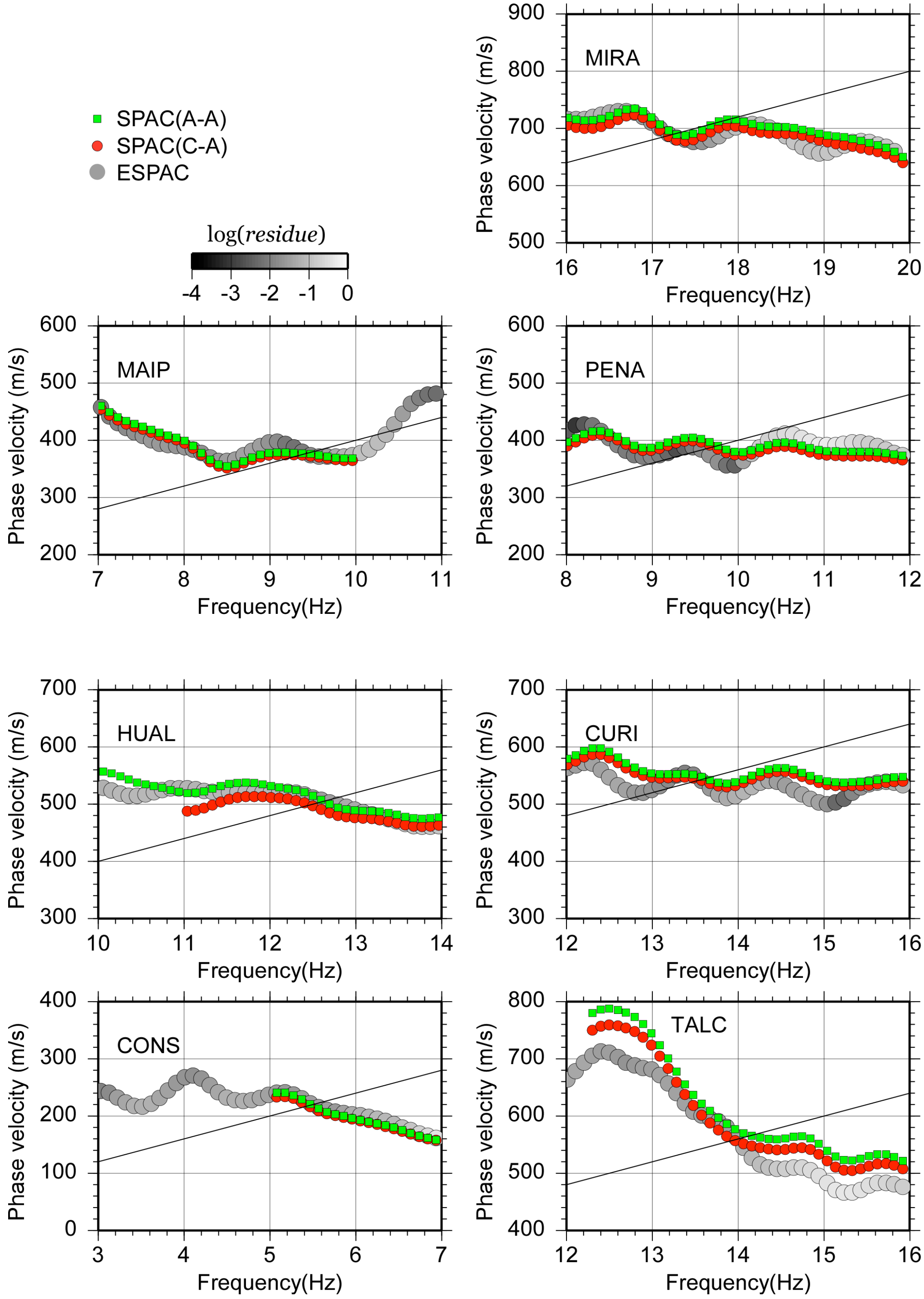

Figure 4. Close view of estimated phase velocity both SPAC method (green and red mark) and ESPAC method (gray circle). Accuracy of estimated value is represented by gray darkness. Guide line also displayed.

Finally, the Vs30 of each site is summarized in Table 2. These values are ranged from 220 m/s to 680 m/s. Generally speaking, these values are larger than those of Japan, except CONS site. In Japan, a site which Vs30 is 600 m/s is treated as a bedrock site basically. When we apply peak values in Chile to Japanese empirical attenuation relation, these six sites should be treated as a stiff site.

Table 2. The Vs30 of each site.

code	Vs30	HPGA (cm/s/s)	HPGV (cm/s)
MAIP	375	550	44
MIRA	685	228	19
PENA	390	390	29
HUAL	500	443	39
CURI	540	465	32
CONS	220	614	69
TALC	560	462	33

DISCUSSIONS

Boroschek *et al.* (2010) summarize peak ground acceleration and peak ground velocity those are obtained their own network in the report. In Table 2, PGA and PGV are also listed. Figure 5 shows relationship between Vs30 and two peak values. We can see the clear tendency that the Vs30 become higher, the peak values becomes smaller. This tendency is stronger in PGV than those of PGA.

Ground motion is affected by not only site effect but propagation effect. There is a possibility that the tendency in Fig.5 is just apparent. For three stations in Santiago, distances from fault plane or energy release area on the fault to the stations is assumed to be the same. We can neglect propagation effect for three stations. Only for the three stations, relation of peak values and the Vs30 are displayed in Figure 6. In the Figure, empirical PGV amplification factor proposed by Midorikawa *et al.* (1994) is also displayed. The appearance is the same to Fig.5. Higher Vs30 has lower peak value. However, we should say that this tendency is qualitative nature but not quantitative nature. Station MAIP and PENA has almost the same Vs30, while peak value of station MAIP is clearly bigger than those of PENA. This phenomenon will not be explained by only Vs30 value.

High peak value at MAIP will be explained as follows. From the figure 3, we can point out that phase velocity of MAIP in lower frequency is higher than those of PENA. This means that MAIP has a higher velocity layer at the below the site. Figure 7 is a horizontal to the vertical ratio of microtremor spectral at MAIP and PENA. At MAIP, there is a sharp peak around 3Hz and deep trough around 6Hz. This shape comes from sharp impedance contrast. On the other hand, at PENA, there is no peak in the spectral ratio. Afore mentioned facts indicate that sharp impedance contrast at MAIP amplifies ground motion and causes high peak value. We can realize that the Vs30 is not a magic number. If we should make a detail study of site effect, clearing the soil profile is essential.

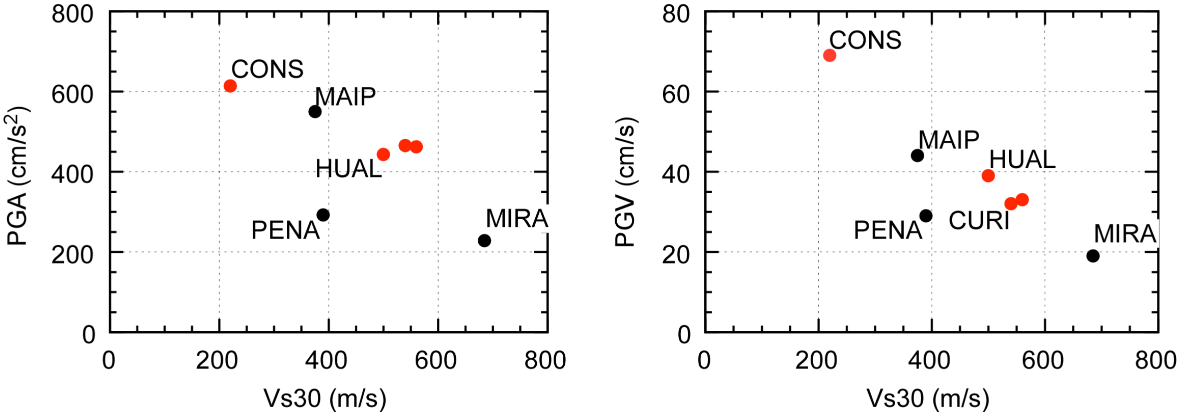

Figure 5. Relation between Vs30 and Peak ground acceleration (left hand side) and peak ground velocity (right hand side). Black solid circle indicate that the site is around Santiago.

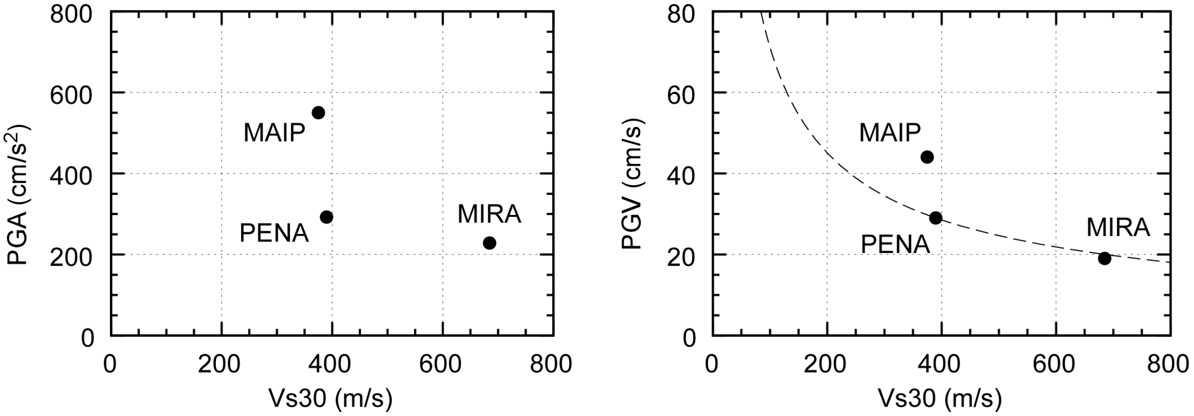

Figure 6. Same to the Fig.5 but only three stations in Santiago is illustrated. Broken line in right hand side panel is the empirical amplification relation proposed by Midorikawa et al. (1994) . As this relation is amplification factor, vertical axis is an arbitrary.

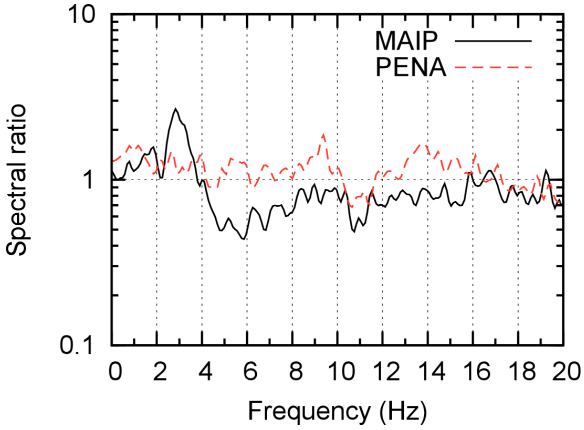

Figure 7. Horizontal to the vertical spectral ratio obtained at MAIP and PENA.

CONCLUDING REMARKS

To evaluate a site effect, microtremor exploration was performed at seven strong motion observation stations in Chile. In this paper, an average S-wave velocity for top 30 meter (Vs30) is estimated from phase velocity that is obtained by microtremor exploration. These values are ranged from 220 m/s to 680 m/s. Station at Constitution has the lowest values. Others have high values those are treated stiff site in Japan.

Then a relationship between the Vs30 and peak ground values is studied. The higher Vs30 site has lower peak value, basically. However, by studying peak values observed in Santiago, we find out that two stations those Vs30 is almost the same has different peak values. The Vs30 is not a perfect index to estimate the ground amplification. If we should make a detail study of site effect, clearing the soil profile is essential.

ACKNOWLEDGEMENT

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