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SPATIAL EVALUATION OF SITE EFFECTS IN ASHIGARA VALLEYBASED ON S-WAVE VELOCITY STRUCTURESDETERMINED BY ARRAY OBSERVATIONS OF MICROTREMORS

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SUMMARY

It is most important to understand underground structures for understanding the spatial variation of ground motion. As we have learned from the 1995 Hyogo-ken nanbu earthquake, the deep (1~2 km) two-dimensional underground structures gave most important effects on the severity of earthquake ground motion. Uetake and Kudo (1998) indicated a strong variation of long period ground motion near the center of Ashigara Valley. They considered that the reason is due to deep underground structure. Therefore, to capture the underground structure in terms of two or three dimension is one of the key parameter for seismic hazard assessment in an urban area.

We carried out array observations of microtremors in Ashigara valley and determined the S-wave velocity structures using the phase velocity dispersion of Rayleigh wave included in microtremors. We compared the S-wave velocity structure model derived from the array observations of microtremors with the previous structure models determined by refraction and reflection surveys and PS logging. As a result, our model is in good agreement with the previous models as far as the deep underground structures are concerned.

Moreover, we computed waveforms based on 1D propagation theory for two underground structure models determined by PS logging and array observation of microtremors and compared them with the observed waveform. Both theoretical and observed waveforms are in good agreement. We conclude that the S-wave velocity structure model determined by array observations of microtremors is useful for the site characterization of earthquake motion.

INTRODUCTION

As we have learned from the 1995 Hyogo-ken nanbu earthquake, the deep (1~2 km) two-dimensional underground structures gave most important effects on the severity of earthquake ground motion. Therefore, to capture the underground structure in terms of two or three dimension is one of the key parameter for seismic hazard assessment in an urban area.

The Ashigara Valley and its vicinity have been suffered from moderately large (M~7) and very large earthquakes (M~8) roughly every 70 years and some seismologists have anticipated the occurrence of large (M~7 or 8) event in the very near future (e.g., Ishibashi, 1985). Therefore, assessments of severity of strong earthquake motion are inevitable and understandings of the spatial variation due to the difference of underground structure are urgent issues in this area. Uetake and Kudo (1998) indicated a strong variation of long period ground motion near the center of Ashigara Valley. They attributed the variation of ground motion to deep underground structure in Ashigara valley.

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Several methods of seismic prospecting such as, PS logging, and refraction and reflection survey have been used for estimating underground structure. However, to determine the structure model by seismic prospecting such as reflection or refraction survey requires a lot of finance and we sometimes encounter difficulties to carry out such experiments in urban area due to artificial seismic sources. In addition, the determination of S-wave velocity structure needs much effort compared with the P-wave case.

In order to overcome the above difficulties, we applied the array observations of microtremors for estimating the S-wave velocity structures. Horike (1985), Matsushima and Okada (1990) have successfully carried out array observations of microtremors in urban areas, as a pioneering work. We applied the SPAC (Spatial Auto-Correlation) method (Aki 1957, Okada 1999) for determining the phase velocities of Rayleigh waves included in vertical component of microtremors. The S-wave velocity structures are obtained from the phase velocity dispersion in a layered structure. In this paper, we compared the S-wave velocity structures estimated by microtremors with the results of the P-wave refraction and reflection survey. We also made a comparative studies using computed waveforms based on 1-D propagation theory for two underground structure models determined by PS logging and array observation of microtremors. We discuss on an applicability of underground structures determined by the array observations of microtremors in estimating site effects on earthquake motion.

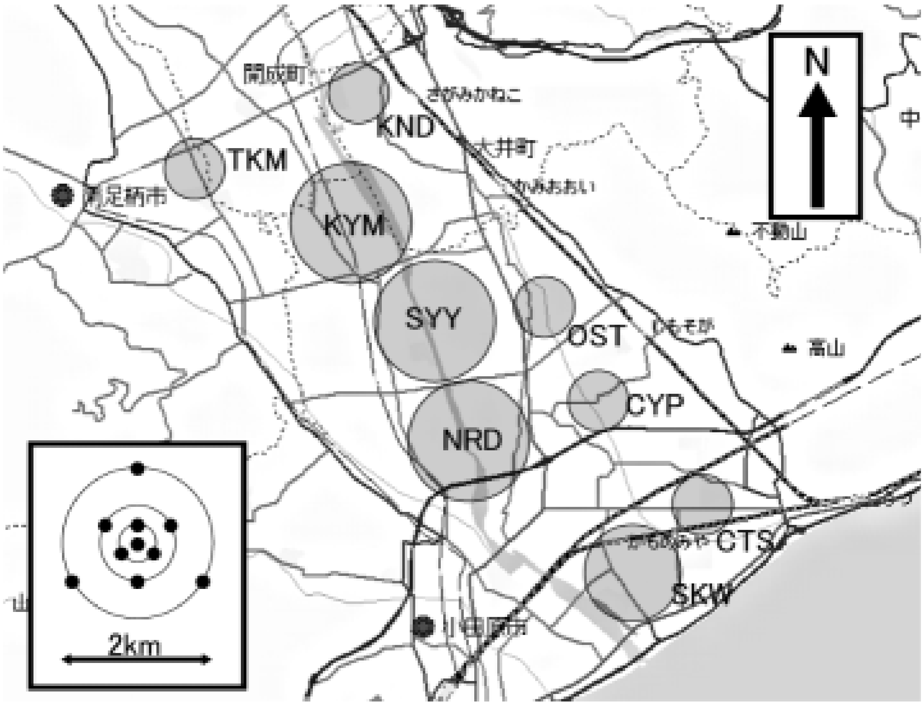

Figure 1: Location map of array observations of microtremors and a configuration of array

OUTLINE AND RESULTS OF OBSERVATION

We carried out array observations of microtremors in December 1997, May and August 1998. Figure. 1 shows observed areas and Table 1 shows details of observations conducted at each area. We used a set of portable seismic instruments that consist of a tri-axial accelerometer (JEP-6A3: Akashi) and 24bit loggers (DATAMARK LS-8000WD: Hakusan Kogyo). We used a low pass filter having a cut off frequency of 10Hz and a sampling frequency of 50. A clock of each logger was synchronized by GPS time signal before observation. Observations at one site were carried out two times with different sizes of array that consists of two or three different radius, as shown in Figure 1.

As an example of these observations results, waveforms and power spectra of the small array at SSY and large array at CTS are shown in Figure 2. The waveforms show integrated velocities using a band pass filter (0.1~10Hz). In case of SYY time variations of microtremors are stable and correlations between stations are very good. On the contrary, time and spatial variations are unstable in case of CTS. We did not use these data in the following analysis

Table 1: Detail of Observations in Each Area (*: [] not use for analysis)

Area	Period	Time	Radius of array (m)*		Magnification of amplifier	Number of instruments
			Small array	Large array		
KYM	1997.12	Daytime	25 50 100	200 400 800	200	10
SYY	1997.12	Daytime	25 50 100	200 400 800	200	10
NRD1	1997.12	Daytime	25 50 100	200 [400 800]	200	10
CTS	1998.5	Daytime	50 100	[200 400]	200	7
SHJ	1998.5	Daytime	50 100	200 400	200	7
NRD2	1998.8	Early morning	150 300	300 600	2000	7
OST	1998.8	Early morning	50 100	200 400	2000	7
CYP	1998.8	Daytime	50 100	200 400	2000	7
SKW	1998.8	Early morning	20 40 80	160 320 640	2000	10
TKM	1998.8	Early morning	50 100	200 400	2000	7
KND	1998.8	Daytime	50 100	[200 400]	2000	7

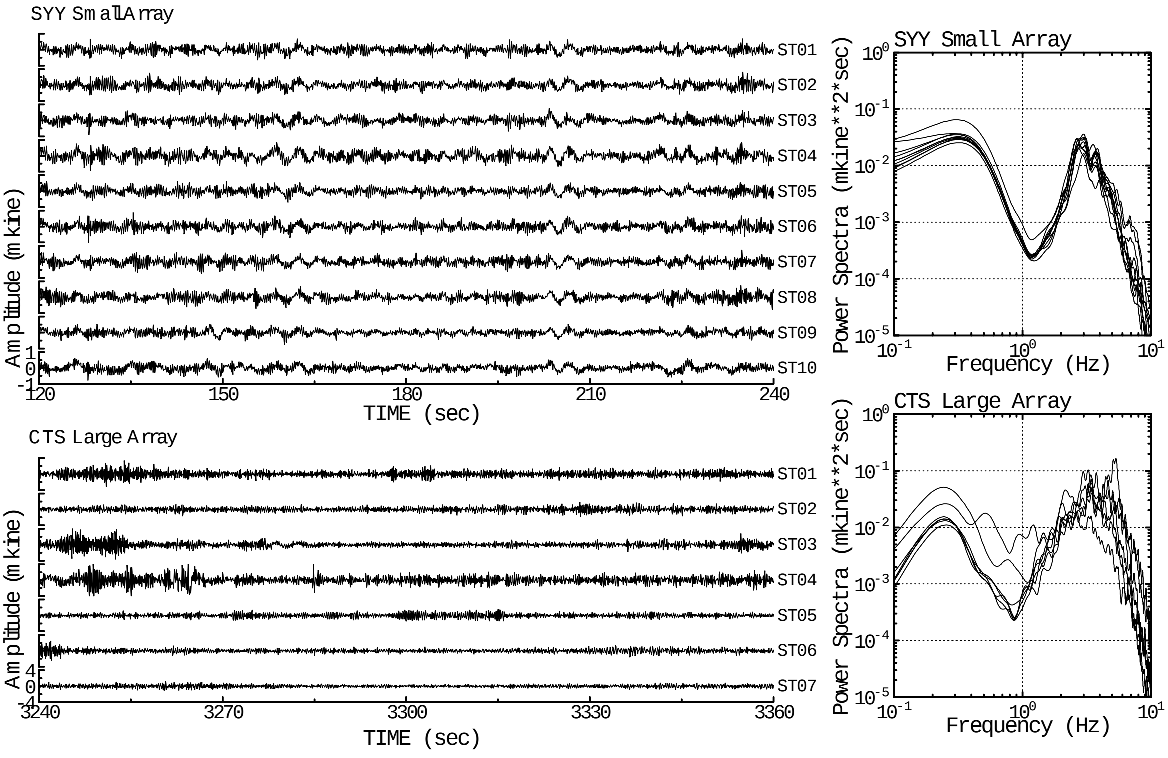

Figure 2: Waveforms (integrated velocity) of observed microtremors and their power spectra.

OUTLINE OF ANALYSIS

We used Spatial Auto-Correlation Method (SPAC method, Aki 1957, Okada 1999) to determine phase velocity of Rayleigh wave from observed microtremors. At first we integrated observed acceleration using a band pass filter (0.1~10Hz). Next, we divided the data into every 4096 samples and analyzed selecting 25~40 stable parts. Figure 3 is examples of computed SPAC coefficient as a function of frequency. The ordinate and the abscissa show SPAC coefficient and a distance between two stations, respectively. The circles in this figure are observed values and solid line is the first kind zero order Bessel function fitted against observed values using the least squares method. An accurate phase velocity can be given in case of small error in the fitting. Therefore, we did not compute phase velocity for some frequencies that have a large error in the to the Bessel function against observed values like 0.2Hz in Figure 3.

Thus determined phase velocities of Rayleigh waves at every site are shown in Figure 4. The difference of analyzable frequency band for determining phase velocities at every site may come from the differences of array radius and less power of microtremors or low S/N ratio of instruments.

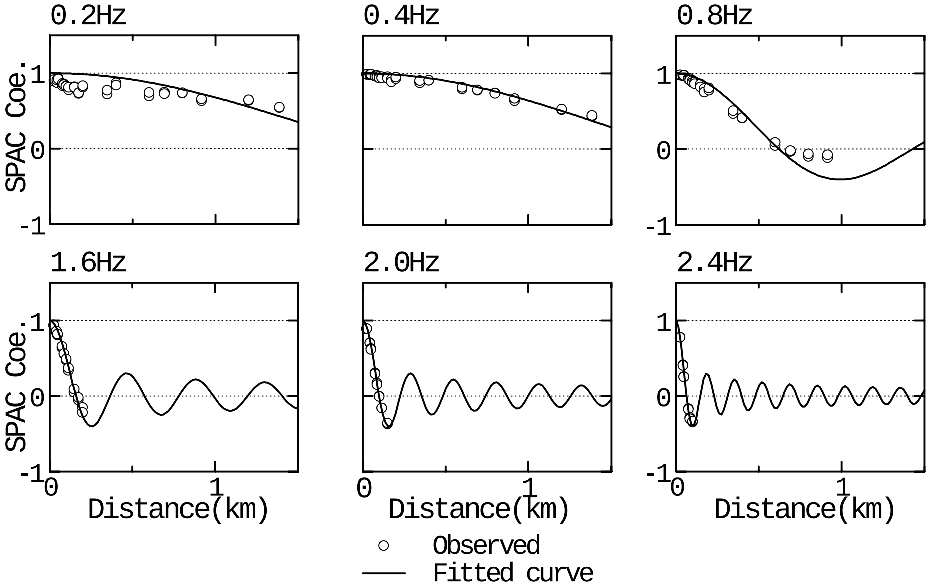

Figure 3: Observed SPAC coefficients and the Bessel functions fitted to them.

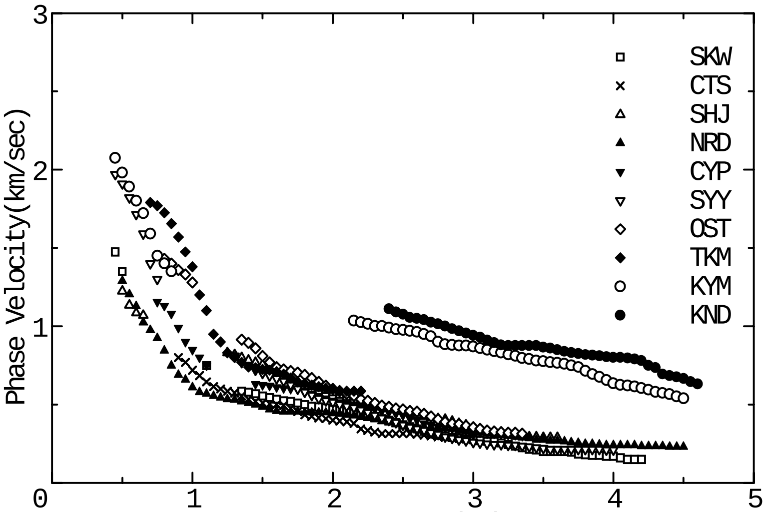

Figure 4: Obtained phase velocity dispersions of Rayleigh wave at every site.

ESTIMATION OF S-WAVE VELOCITY STRUCTURES

We used trail and error method for estimating S-wave velocity structure using observed phase velocity dispersion of Rayleigh waves. At first, we make an initial model of S-wave velocity structure referring to some existing structure models. Then we compare a theoretical dispersion curve computed using the model with the observed phase velocity. We iterate this procedure until that a theoretical dispersion curve matches with the observation by manually modifying a structure model. Figure 5 shows the theoretical dispersion curves (solid lines) fitted to the observed phase velocity (circles) at every site and the final models of S-wave velocity structure. In case of CTS, we could not obtain phase velocities at lower frequency than 0.7 Hz. Therefore, we substituted the phase velocities at SHJ and SKW near CTS. Because of poor quality of data at KND for low frequency band and at TKM for high frequency band, we have little information on underground structures beneath these sites. We will carry out observation at these sites again. We referred the deep structure model proposed by Uetake and Kudo (1998) as a constraint for inverting phase velocity to S-wave velocity structure.

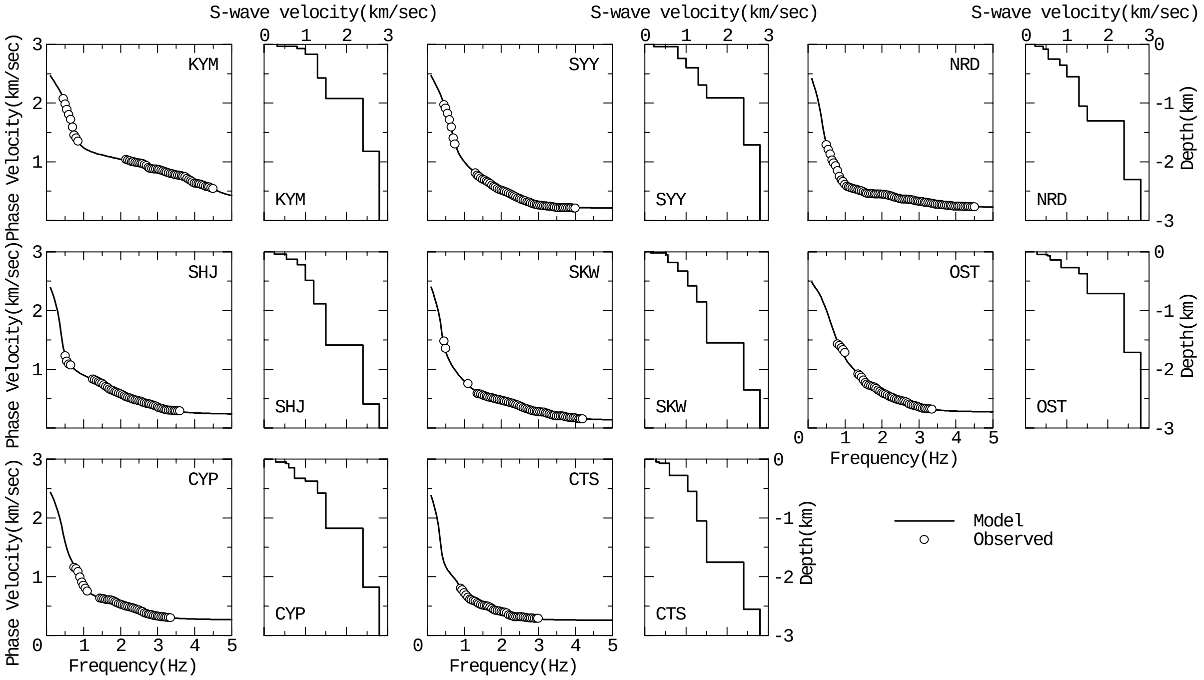

Figure 5: Dispersion curves fitted to the obtained phase velocities and estimated S-wave velocity structures.

COMPARISON ESTIMATED MODEL WITH THE PREVIOUS MODEL

Some results of seismic prospecting in Ashigara valley have been published. Higashi (1989) modeled the P-wave velocity structure for north-south section in the valley including KYM and SHJ based on a refraction method. It is a two-layer model having the first layer of 2.2km/sec and the second layer of 3.0km/sec. A reflection survey was also carried out near SHJ and an east-west cross-section was obtained (J-ESG 1991). In addition, PS logging to a depth of 500 m was carried out at CTS and the results are shown in Table 2.

Figure 6 shows the P-wave velocity structure model determined by Higashi (1989) and the S-wave velocity structures at KYM, SYY, NRD and SHJ estimated from array observations of microtremors. We may say that the estimated S-wave velocity structures do not necessarily correspond to the P-wave model. However, features that the thickness of sediments increases gradually from north (KYM) toward south (NRD) of the valley and decreases toward SHJ are identical. Figure 7 is a comparison between the cross-section obtained by reflection survey and our S-wave velocity structure model at SHJ. We also indicate that the depth to a basement layer (Vp=3.2km/sec, Vs=1.5km/sec) and interfaces of each layer are well correlate between two models. Therefore, we may conclude that S-wave velocity structures determined by array observations of microtremors are reliable as far as that deep underground structures are concerned. Figure 8 compares the dispersion curve calculated using the underground structures determined by the PS logging with the observed phase velocities of Rayleigh wave obtained by array observation of microtremors. A good agreement is suggested at lower frequency than about 1.3 Hz, however less matching is found at higher frequency than 2.2 Hz. The less matching is discussed later.

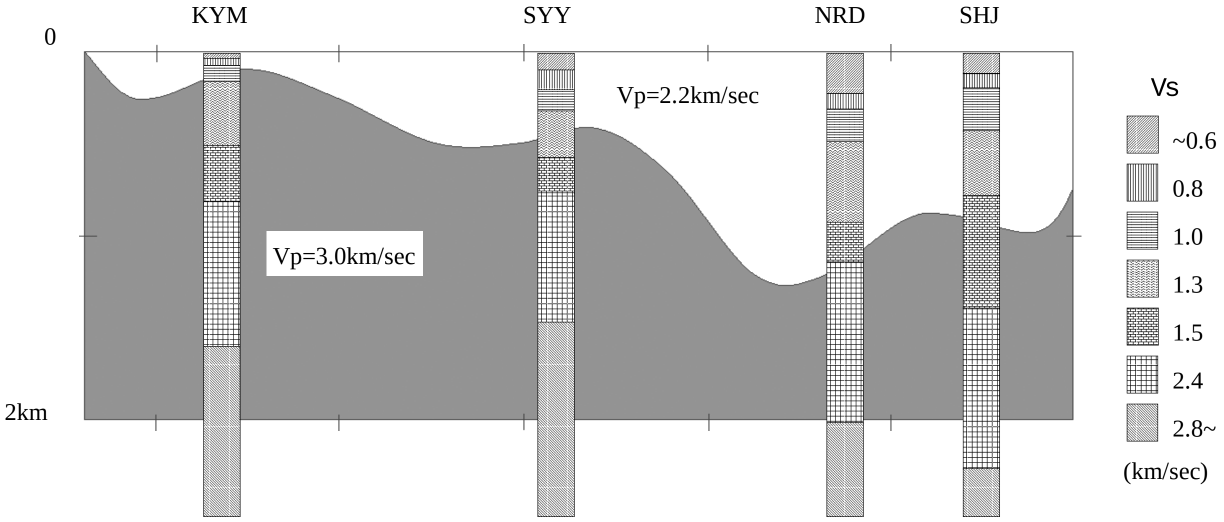

Figure 6: Comparison estimated S-wave velocity structures with underground structures model by the refraction survey (Higashi 1989).

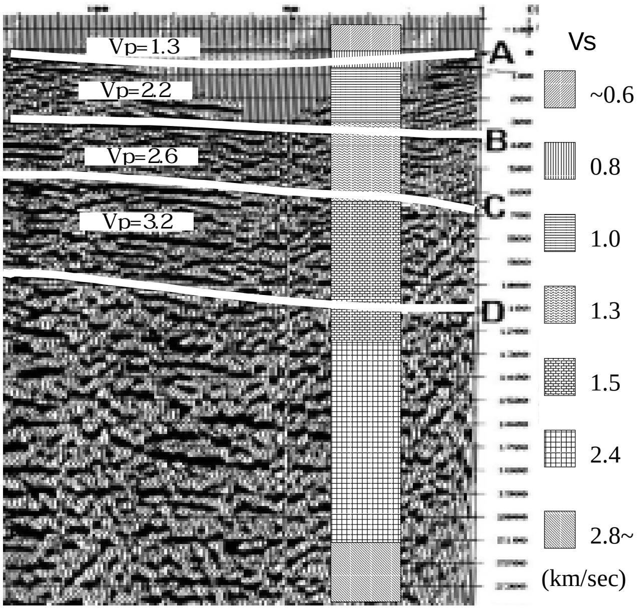

Figure 7: Comparison estimated S-wave velocity structures with underground structures model by the reflection survey (J-ESG 1991) at SHJ.

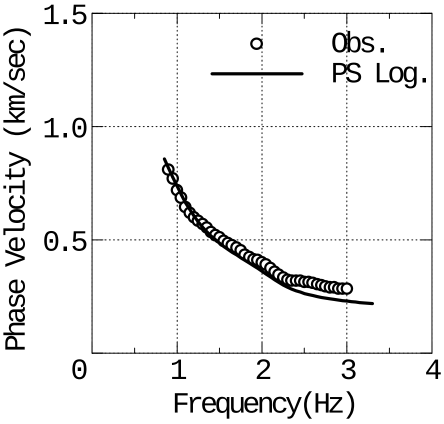

Figure 8: Comparison phase velocity of Rayleigh wave derived from microtremors with dispersion curve computed from the result of PS logging at

CTS.DISCUSSION BASED ON 1-D WAVE PROPAGATION THEORY

We discuss the earthquake ground motions observed by vertical array of strong motion instruments at depths of 10, 30, 100 and 467m as well as at surface at CTS. We estimate the ground motion at surface using earthquake motion at depth of 467m and the structure models based on 1-D propagation theory of SH wave. Two structure models obtained by PS logging and array observations of microtremors are used, as shown in Table 2. Qs values estimated by Saito et al. (1995) are used. Figure 9 shows theoretical transfer functions calculated from two models and a spectral ratio of observed earthquake motions between surface and the bottom (-467 m). We use the earthquake motions of transverse component from the west Knangawa prefecture earthquake (Mj=5.1), of August 5, 1990. The theoretical transfer function by the model of PS logging (thin solid line) matches with the observation (thick solid line). However, that of microtremors (thin broken line) has significant difference of large troughs at around 1.7 and 2.6Hz that were not found in observed spectral ratio. The very shallow layers seem to contribute these differences. One possibility of the discrepancy is due to heterogeneity near surface underground structure that influences phase velocities of short wavelength, that is, the array size was too large to determine phase velocities accurately in high frequency range. In this paper, we modified the model estimated by microtremors referring to a surface layer of the PS logging model, as shown in Table 2. A transfer function computed using the modified model is shown by a thick broken line in Figure 9.

Figure 10 shows computed waveforms based on two theoretical transfer functions and the observed surface motion taking the observed earthquake motion at a depth of 467m as an input motion. Cross-correlation between two computed motions and the observation are also plotted in the figure. The early arrivals of S-wave of two computed motions coincide with the observation, but correlation of later arrivals become worse. It is uncertain why this discrepancy comes from, however, plausible reasons will be insufficient modeling of subsurface structure, influence of surface wave generated by 2D or 3D underground structure and assumption of vertical incidence of waves. Figure 11 shows the Fourier spectra of two computed motions and the observation for the early arrivals of S-wave. Fourier spectrum by the array model is in agreement with the observed one as well as the PS logging model.

Table 2: S-wave velocity structure models at CTS

PS logging model			Microtremors (initial model)		Microtremors (modified)	
Vp (m/s)	Vs (m/s)	Thickness (m)	Vs (m/sec)	Thickness (m)	Vs (m/sec)	Thickness (m)
800	110	11	270	52	130	15
1320	220	12	350	20	295	35
1400	250	27	600	205	350	33
1900	500	7	1040	275	600	205
1650	270	11	1260	Inf.	1040	275
1960	560	22			1260	Inf.
2250	790	150				
2350	970	180				
2520	1260	Inf				

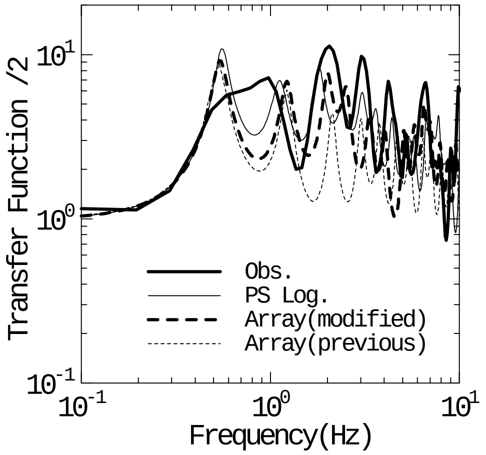

Figure 9: Comparison between theoretical transfer functions of two models by PS logging and array observations of microtremors and observed spectral ratios between surface and -467 m.