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STUDY ON MICROTREMOR CHARACTERISTICS BASED ON SIMULTANEOUS MEASUREMENTS BETWEEN BASEMENT AND SURFACE USING BOREHOLE

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SUMMARY

It’s very important to derive the ground shaking characteristics, predominant period and amplification factor, from the microtremor observation results in order to estimate the dynamical behaviour of structure for seismic resistant design and seismic microzoning for the damage assessment due to future predicted earthquake. Recently, in order to derive the ground shaking characteristics, the microtremor measurements are performed, especially by observing the three components at ground surface and using Nakamura’s Technique, H/V Spectrum. This technique has been developed in the world in order to evaluate the ground shaking characteristics. H/V spectrum means the spectral ratio between the horizontal and vertical component, and there are very important hypothesis lied under this technique. The first is that the main waves are Rayleigh Waves and the second is that the soil structure is assumed to the horizontally layered structure and the third is that there appears a big contrast between the basement and sedimentary layer. But generally, it’s very difficult to do the microtremor measurement by confirming the soil structure and using the borehole located above mentioned idealized soil structure. The purpose of this paper is performing an experimental research work for understanding the microtremor characteristics, applicability and limitation of H/V spectrum based on simultaneous measurement between basement and surface using borehole.

INTRODUCTION

The characteristics of microtremors and the applications to earthquake engineering in order to evaluate the site effects, predominant period and amplification at the site, have been discussed quite often since the 1985 Mexico Earthquake. In Mexico City, after the 1985 Mexico Earthquake, microtremor measurements were done at many sites and the characteristics of microtremors seemed very clear so that the comparison of strong motion records and measured microtremors at the same sites showed good agreement each other [Kobayashi et al., 1986, Lermo et al., 1988]. But in general, microtremors should not be expected so much because local soil conditions are not so simple. For this reason, several trials have been made in different conditions with different approaches. Nakamura [Nakamura, 1989] proposed to take horizontal over vertical spectral ratios (H/V) of microtremors as a substitute for the transfer function of subsurface ground, although there were so many opinions that the physical meaning of taking H/V ratio had not been made clear. This method has been examined by Lachet et al.[Lachet et al., 1994] with numerical and theoretical investigations. After these discussions, H/V spectrum was used in many cases of microtremor measurements studies at many sites in the world because of its stability. Joint measurements of microtremors to discuss the results among the participants have been examined in the Ashigara Valley, Kanagawa Prefecture, as one of research activities on the effects of surface geology on seismic motion (ESG). The similar examination were also attempted in the Kushiro area, Hokkaido, after the 1993 Kushiro-oki Earthquake [Seo, 1994], and in the Kobe-Hanshin region after the 1995 Hyogoken-Nanbu Earthquake [Seo et al., 1996]. In these joint research works, there were so many microtremor measurement sites using moving

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observations at surface every several hundreds meters interval in order to identify the difference of ground shaking characteristics. So the results obtained from H/V spectra was very useful for recognition of site effects and very good agreement with the surface conditions.

In this paper, we observed microtremors at basement and surface using the borehole at two sites. The soil structures of both sites were identified from SPT and PS Logging Test and we confirmed the very different soil situation in each other. The first site is located in Niigata City (NGT), where is a large flat plain and very famous due to liquefaction phenomena occurred in the 1964 Niigata Earthquake. The second site is located at Zushi City (ZSH), where is a small valley and also affected serious damages by the 1923 Great Kanto Earthquake. NGT site has the deep sedimentary layer, mainly constituted by sand, and the depth of borehole is about 130m deep up to the stable gravel layer where is not still a consolidated layer and there is not so big contrast between the bottom layer and sedimentary layer. ZSH site has the shallow sedimentary layer and the depth of borehole is about 20m deep up to the stable basement rock layer where is a consolidated layer. And there is a clear contrast between the basement rock and sedimentary layer. According to these microtremor measurements, we obtained the ground shaking characteristics more clear at ZSH site than NGT site. We would like to present the microtremor characteristics by using the data obtained from both borehole sites and also discuss about the applicability and limitation of H/V spectrum for understanding the ground shaking characteristics.

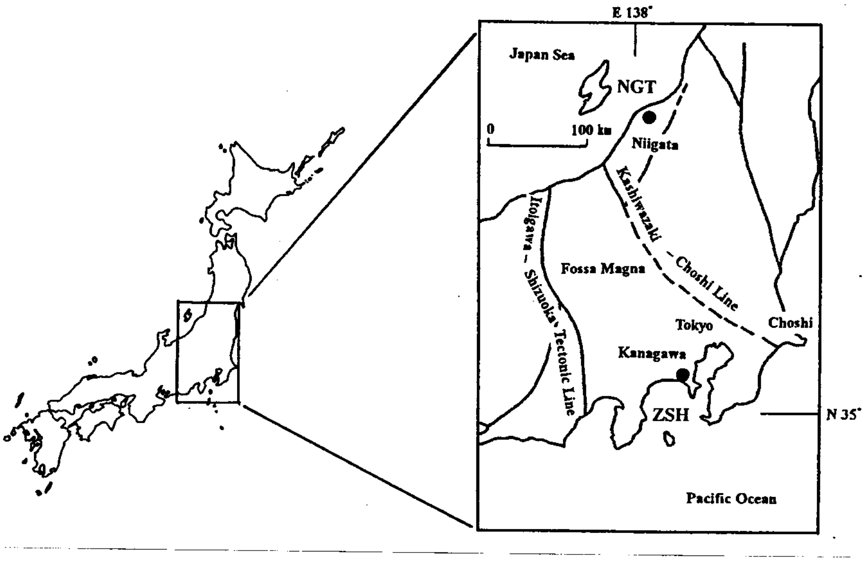

Figure 1. Locations of ZSH and NGT sites.

SOIL STRUCTURE OF ZSH AND NGT SITE

The locations of ZSH and NGT sites are indicated in Figure 1. The soil profile and the results PS Logging Test at ZSH and NGT sites are shown in Figure 2. At ZSH site, the soil profile is very simple because there located the basement rock constituted by mudstone and sandstone under the very soft layer constituted from alluvial sand and silt. The depth of the upper most soft soil layer, the thickness is about 16m, shows that the P-wave velocity is about 1300m/sec and the S-wave velocity is about 130m/sec and the basement rock shows that P-wave velocity is about 1800m/sec and S-wave velocity is about 600m/sec from the result of PS Logging Test, this means that the contrast between surface soft layer and basement layer is 1.38 in P-wave velocity and 4.62 in S-wave velocity. So there are very clear contrast in S-wave velocity. Niigata Plain where NGT site is located, is situated near the Fossa Magna. Fossa Magna is the very large and important tectonic boundary which divide the Central Japan Island into two main parts, namely Eastern Japan and Western Japan, so the very stable and hard consolidated rock is located about several thousands meters just under from the surface in this region. The geological condition in the upper most layer constituted from Middle Pleistocene to Holocene, the thickness of this layer is reached to about 1000m, and the relatively stable layer is constituted by gravel just on the buried terrace located from 130m to 150m below from the surface. According to the borehole data shown in Figure 2, the soil profile is very complicated and P-wave and S-wave velocity values are increasing along to the depth.

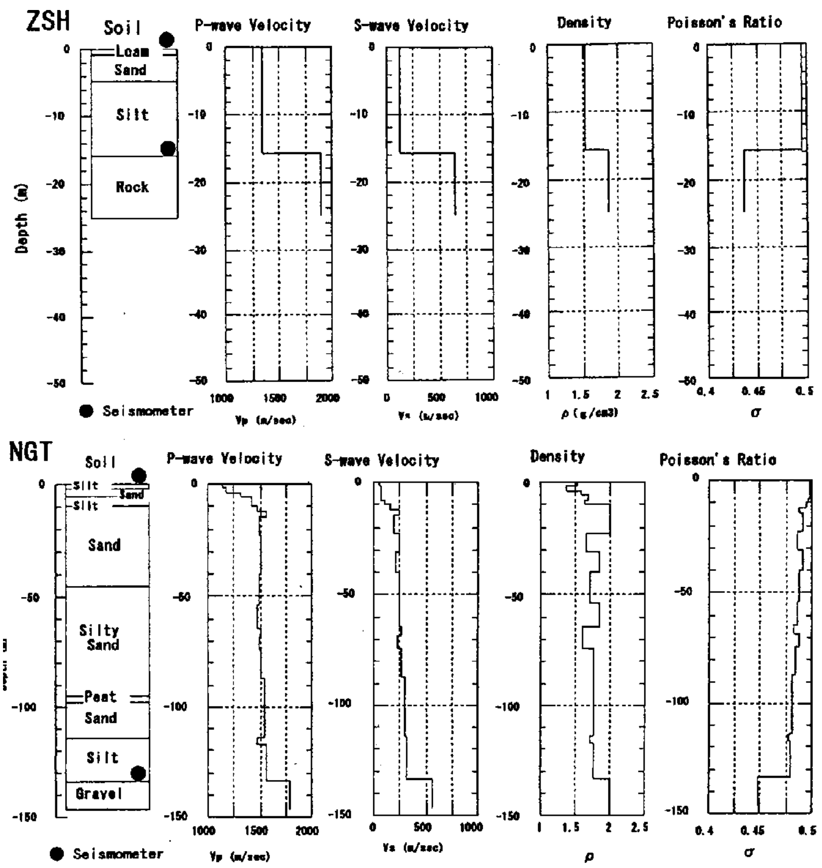

Figure 2. Soil profiles and results of PS Logging Test

Near the surface up to 10m below from the surface, the P-wave velocity is about 1200 – 1300m/sec and S-wave velocity is about 80m/sec. The next lower layer, it's extended from 10m to 135m below from the surface, the P-wave velocity is about 1500m/sec and S-wave velocity is about 250 – 300m/sec. And at the lowest gravel layer, the P-wave velocity is about 1800m/sec, and S-wave velocity is about 550m/sec. The contrast between second lower layer and the lowest gravel layer is about 1.20 in P-wave velocity and about 1.83 – 2.20 in S-wave velocity, then the contrast between the second layer and the lowest layer is not clearer than this value obtained at ZSH site.

MICROTREMORS MEASUREMENTS

Microtremor measurements were done simultaneously at the surface and the basement layer in the borehole at ZSH and NGT sites respectively. The equipment used for the measurement system are same at both sites. At the surface, UPS-255S and UPS-T3 (Natural period is 1.0sec and 5.0sec changeable), moving coil velocity type seismometer and at the bottom of borehole, KGU-SP (Natural period is 2.0sec), moving coil velocity type seismometer were used in the microtremor measurements. The date and conditions of mocrotremor measurements at ZSH and NGT sites are listed up in Table 1.

At ZSH site, microtremor measurements were done from 16:00 of 21 August, 1998 to 7:00 of 22 August, 1998. In this case, we have done the 10 minutes measurements with three components which are North-South (NS), East-West (EW) and Up-Down (UD) components every one hour interval during 16 hours. And at NGT site, we have done the 15 minutes measurements two times in the afternoon and morning, one was started at 12:30 of 24 June, 1998 and the other was started at 6:45 of 25 June, 1998 using short period range and long period range respectively. The data acquisition is used 100Hz sampling and recorded by 16bits digital data recorder. The samples of measured microtremor waveforms are shown in Figure 3. Using these recorded microtremors, we calculated the Fourier Spectra including smoothing technique by Parzen's window which has 0.3Hz frequency band width using FFT method after selecting the 30 seconds time window of every 10 and 15 minutes measurements at ZSH and NGT site respectively. The results of Fourier Spectra are shown in Figure 4

Table 1. Date and conditions of microtremor measurements at ZSH and NGT sites

ZSH Site

Measurement	Measured Time	Duration Time	Period Range
Z01-B&S	1998/8/21/16:00	10 min.	Short
Z02-B&S	1998/8/21/17:00	10 min.	Short
Z03-B&S	1998/8/21/18:00	10 min.	Short
Z04-B&S	1998/8/21/19:00	10 min.	Short
Z05-B&S	1998/8/21/20:00	10 min.	Short
Z06-B&S	1998/8/21/21:00	10 min.	Short
Z07-B&S	1998/8/21/22:00	10 min.	Short
Z08-B&S	1998/8/21/23:00	10 min.	Short
Z09-B&S	1998/8/22/00:00	10 min.	Short
Z10-B&S	1998/8/22/01:00	10 min.	Short
Z11-B&S	1998/8/22/02:00	10 min.	Short
Z12-B&S	1998/8/22/03:00	10 min.	Short
Z13-B&S	1998/8/22/04:00	10 min.	Short
Z14-B&S	1998/8/22/05:00	10 min.	Short
Z15-B&S	1998/8/22/06:00	10 min.	Short
Z16-B&S	1998/8/22/07:00	10 min.	Short

NGT Site

Measurement	Measured Time	Duration Time	Period Range
OKY02-B&S	1998/6/24/12:30	30 min.	Short
OKY03-B&S	1998/6/24/13:40	15 min.	Long
OKY04-B&S	1998/6/25/06:45	15 min.	Short
OKY05-B&S	1998/6/25/07:15	15 min.	Long

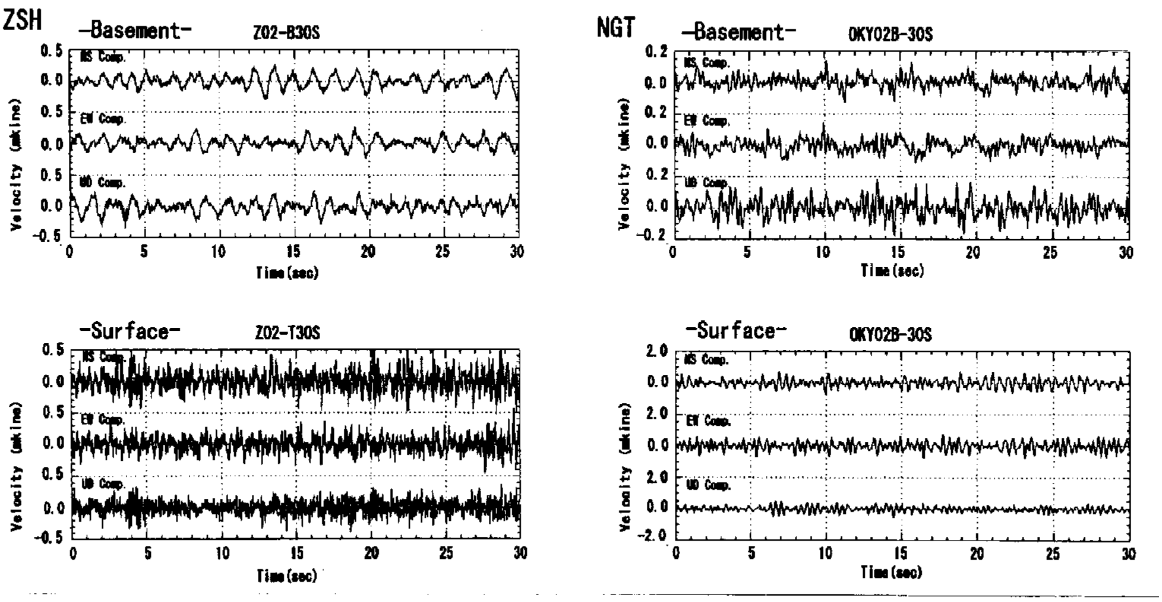

Figure 3. Examples of wave form microtremors observed at basement and surface simultaneously.

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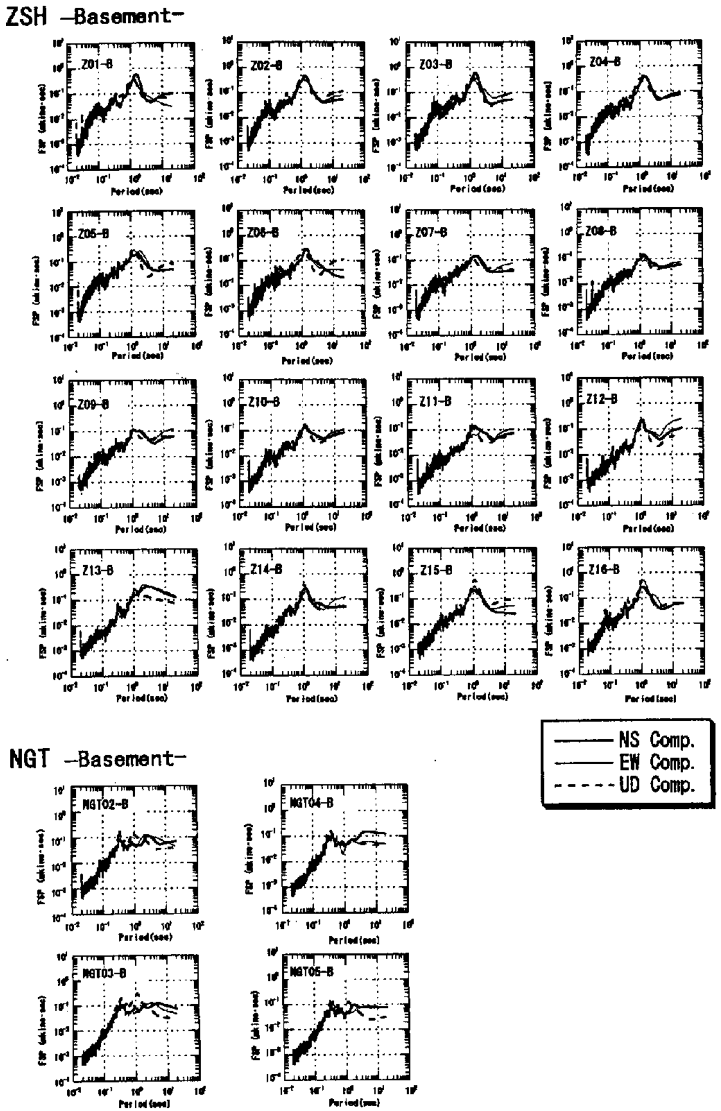

Figure 4. (a) Fourier spectra of observed microtremors at basement in ZHS and NGT sites.

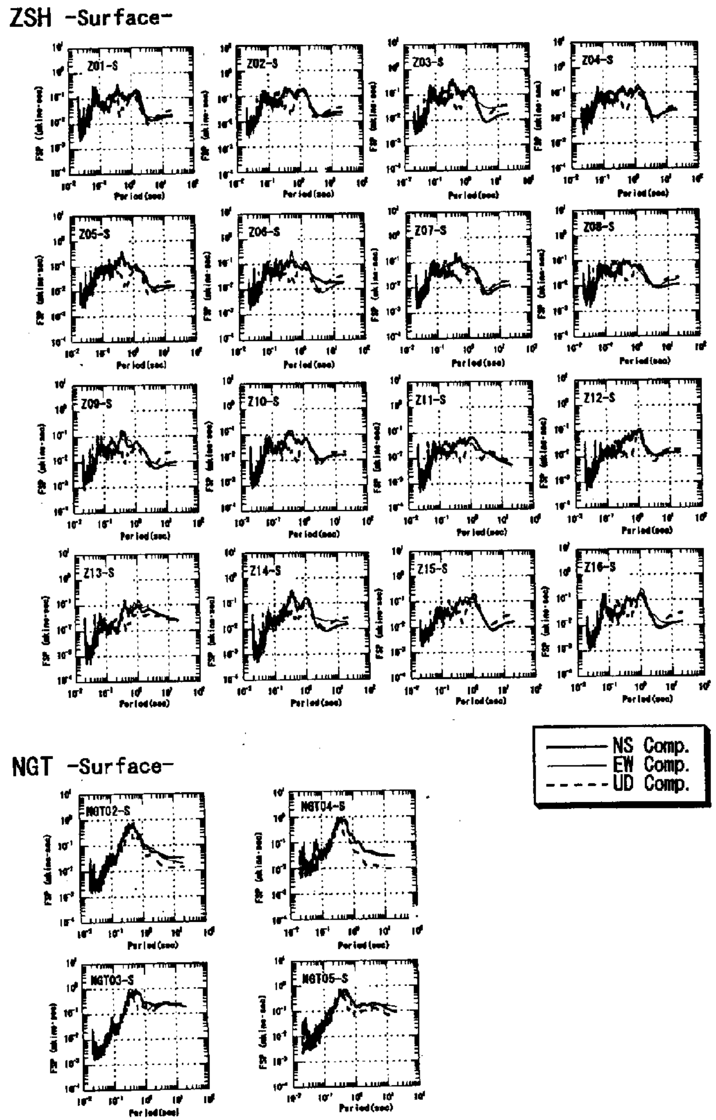

Figure 4. (b) Fourier spectra of observed microtremors at surface in ZHS and NGT sites.

H/V SPECTRA

We calculated the H/V spectra using Fourier Spectra of every measured microtremors in 3 components at ZSH and NGT sites. The results of H/V spectra are shown in Figure 5. At ZSH site, as shown in Figure 5, the results of H/V at every hour are very stable and shown a very similar characteristics at the surface and basement layer respectively. And at the basement layer, the characteristics of H/V spectra is almost flat and the ratio in vertical axis indicates almost 1.0 in this analysis period range from 0.02sec. to 20.0 sec. Although at the surface, the characteristic of H/V spectra appears a very clear peek at 0.4sec. - 0.5sec. The other hand, at NGT site as shown in Figure 5, there are not so clear and stable tendencies in comparison with the case of ZSH site at the both measured positions which are the surface and bottom layer in the borehole. But in the daytime and nighttime measurements and also in short period range and long period range measurements, the period characteristics of H/V spectra are appeared similar tendencies divided into the bottom layer and the surface respectively. These tendencies are not so clear but, at the bottom layer, the period characteristics of H/V spectra are a little bit flat and the value of Ratio is close to 1.0 and at the surface, there appear three peaks in the period characteristics, at about 0.25sec, 0.5sec and 1.5sec.

According to these results, we could understand that the much more clear and stable characteristics due to the site in H/V spectra is appear in results of ZSH where has the simple soil profile and the good contrast in S-wave velocity values between the surface soft soil layer and the basement layer than the results of H/V spectra at NGT site where has a little complicated soil profile and not so clear contrast between upper soil layers and basement upper soil layers and basement layer.

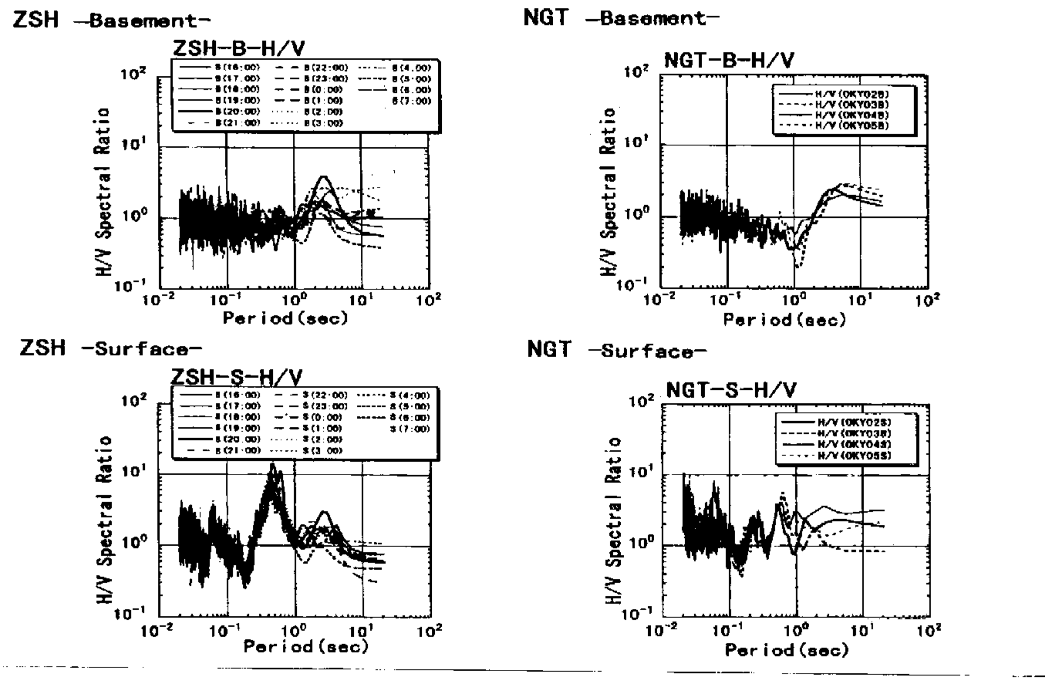

Figure 5. H/V spectra of microtremors observed at basement and surface in ZHS and NGT sites.

TRIPARTITE ARRAY OBSERVATION

H/V spectral ratio obtained at ZSH and NGT sites are indicated stable characteristics as shown in Figure 5. In case of identifying that H/V spectra is coincided to the amplification due to the surface sedimentary soft ground layer using the transfer function generated by SH wave propagation from the basement to the surface, we must confirm that the microtremors are constituted from Rayleigh wave. So, we done the microtremor array observation using tripartite observation system and we investigated the dispersion of phase velocity of microtremors. We used the geometry of tripartite array observation system, equilateral triangle and its one side is set up to about 50m long, at ZSH and NGT sites respectively and recorded only up-down component at each point. Using these observed microtremor data, recorded during 30 minutes and 1000Hz sampling, we have done the band pass filtering at central period put on every 0.1 seconds in the period range from 0.1 seconds to 1.0 seconds. The results are indicated in Figure 6 with the theoretical results of phase velocity dispersion curve of Rayleigh wave. At both sites, the dispersion of phase velocity appeared in the tripartite array microtremor measurements and we could recognize one of the evidences that the microtremors are constituted from Rayleigh wave. From these results, at ZSH site, the dispersion of phase velocity obtained from tripartite array microtremor observation is coincided to the theoretical phase velocity dispersion curve of fundamental mode Rayleigh wave. At NGT site, the result of the dispersion of phase velocity is indicated much more coincided to the first higher mode than the fundamental mode of theoretical phase velocity dispersion curve because of the complexity of soil structure at NGT site.

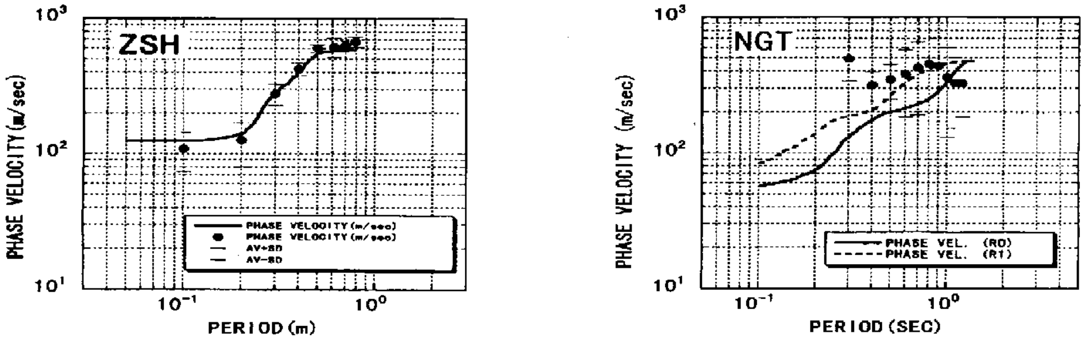

Figure 6. Comparison between theoretical and observed dispersion curve of phase velocity using the results of PS Logging Test and tripartite array observation of microtremors.

TRANSFER FUNCTION

In order to investigate the amplification, we calculated the transfer function using the simultaneous microtremor measurements at basement and surface at ZSH and NGT sites. The theoretical transfer function was calculated by 1-D SH wave propagation analysis used SHAKE program and the observed transfer function was calculated from Fourier spectral ratio obtained from observed microtremor measurements at basement and surface simultaneously using 2-D horizontal component. Figure 7 shows the comparison between the theoretical transfer function and observed transfer function and Figure 8 shows the comparison between theoretical transfer function and H/V spectra. The observed transfer function and H/V spectra indicated in Figure 7 and Figure 8 were evaluated by averaging the observed microtremors which were recorded in continuous and simultaneous microtremor measurement at ZSH and NGT sites respectively indicated as in Chapter 2.

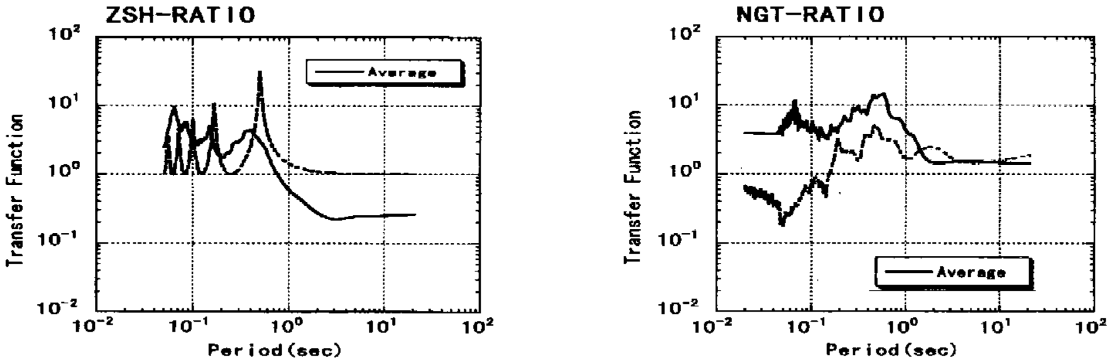

Figure 7. Comparison between theoretical transfer function and observed transfer function.

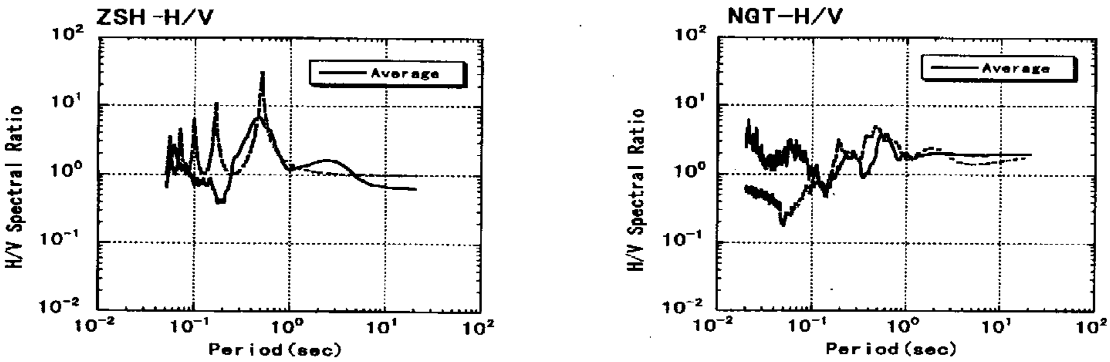

Figure 8. Comparison between theoretical transfer function and H/V spectra.

From these results, H/V spectra is much more coincided to the theoretical transfer function due to SH wave propagation in the surface soil layer than the observed transfer function used simultaneous microtremor measurements between the basement and surface. So, H/V spectra indicates the amplification of SH wave propagation due to the surface soil structure. And it's more clear in case of ZSH site because of the simplicity and the appearance of good contrast between the basement layer and surface soft soil layer.

CONCLUSIONS

We have done the boring and obtained the soil profiles and the results of PS Logging Test at ZSH and NGT sites. And at both sites, we have done the microtremor measurements at basement or bottom layer of borehole and at surface simultaneously. The results of this paper are summarized as follows.

(1)The soil profiles at ZSH and NGT sites are very different. ZSH site has a simple and thin soft soil profile in the upper most surface layer and very clear contrast between the soft soil layer and basement rock layer. Although, NGT site has a complicated and thick surface soil layer and not so good contrast between the surface soil layer and bottom layer .

(2)The microtremor measurements were done simultaneously at basement and surface using borehole at both sites respectively and we calculated the Fourier Spectra using these measured microtremors at both sites. The characteristics of Fourier Spectra were much different depending on the measured time between daytime and nighttime, especially the amplitude level is very different at NGT site.

(3)We calculated the H/V spectra using the Fourier Spectra of measured microtremors at both sites respectively. The characteristics of H/V spectra is very stable and different between the result obtained from basement rock layer and surface clearly at ZSH site but these tendencies is not so clearly appeared at NGT site. We thought that such difference is depended on the soil conditions, especially the contrast of S-wave velocity between surface layer and bottom layer.

(4)At both sites, the dispersion of phase velocity appeared in the tripartite array microtremor measurements and we could recognize one of the evidences that the microtremors are constituted from Rayleigh wave. And H/V spectra indicates the amplification of SH wave propagation due to the surface soil structure. And it's more clear in case of ZSH site because of the simplicity and the appearance of good contrast between the basement layer and surface soft soil layer.

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