SITE AMPLIFICATION IN HACHINOHE OBSERVATION SITE, AOMORI, JAPAN: A COMPARISON OF S-WAVES, CODA AND MICROTREMORS SPECTRAL RATIO

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SUMMARY

Six velocity-type strong motion seismographs stations were installed on bedrock and deep-soil deposit in and near Hachinohe city. In order to estimate the site response of observation site, the spectrum of P-wave, S-wave and coda portion of the seismograms obtained from the site is divided by the spectrum of the corresponding portion of the seismogram from reference site for the same earthquake. The amplitude of spectral ratio of coda at the deep soil deposit is larger amplitude than that of P-wave and S-wave. On the other hand, at the shallow subsoil structure, the amplitude of coda are as same as that of P-wave and S-wave. An observation of long-period microtremors at the seismograph stations was made and compared the site response obtained by seismograms to that were calculated. The result from these study are: 1) in the simultaneous observation of microtremors on the bedrock and soil deposit, the predominant periods observed are very stable in time; 2) the predominant period of microtremors on soil deposit does not necessarily always show a correspond to that of seismic waves. But the microtrmors is one of a useful method to estimate site response. To make comparison between the spectrum of microtremors and that of seismic waves, statistical treatment is one of advantageous methods.

INTRODUCTION

Hachinohe city suffered most from Far off Sanriku Earthquake of 1994, and its after shock of 1995.The distribution of the damaged areas are different from main shock and after shock. In order to estimate the site response on deep soil deposit by spectral ratio method . Many methods have been proposed to estimate effects of surface geological conditions on strong ground motion. Takemura et al.(1991) evaluated the amplification factor from strong motion records by analyzing the S-wave portion in frequency range from 1 to 10Hz, and Sasatani et al.(1992) analyzed seismograms from intermediate depth earthquakes, and estimated the site response on long-period ground motion at various sites in Japan. Margheriti L.et al.(1994) and Kato.K et al.(1995) calculate spectral ratio for S-wave and codas to estimate the sites, and compare the coda with S waves. Castro et al.(1990,1995) obtained the site response and source spectrum of P-, S-wave. On the other hand , Nakamura. Y (1989) proposed new technique for estimation to site response used the spectral ratios of horizontal- vertical ratios of microtremors. Javer L. et al.(1994) observed microtremors in Mexico to review the applicability of microtremor measurements to estimate site effect on soil deposit. Zhao B et.al .(1997) compare the ratios of horizontal-vetical ratios of microtremors between the spectral ratios of seismic motions to examine the validity of Nakamura's technique. Sato S et.al.(1998) observed microtremors at 20 strong motion stations and calculate horizontal-to-vertical spectral ratios H/V, and compared them with P-wave, S-wave, and coda window of seismograms and interpret them theoretically.

In order to investigate whether the amplification for microtremors can be a useful method to predict

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characteristics during earthquakes or not, we estimate the sites response at strong-motion observation sites in Hachinohe city by comparing spectral ratios of P-,wave, S-wave and coda for strong-motions with that of microtrmors.

2. OBSERVATION SITES

A location of observation sites in Hachinohe city are shown in Fig. 1. The Hachinohe area is classified by the geological survey into three major blocks according to whether the depth of bedrock is shallow or moderate or deep. The geographical location of the three block is such that the first block is with shallow bedrock (5 to 50 m depth) is placed in the eastern part of Niida River ,the second with the moderate depth bedrock(100 to 150 m depth) between Niida River and Mabechi River and the third with deep bedrock(150 to 800 m depth) in the northern part of Mabechi River. The first block consist of pre-Tertiary sedimentary rock and granite is placed in a mountainous area , which forms the northern border of Kitakami Massif. The third block is the accumulation terrace covered with thick layers of volcanic ash from the Towada and Hakkoda volcanoes.

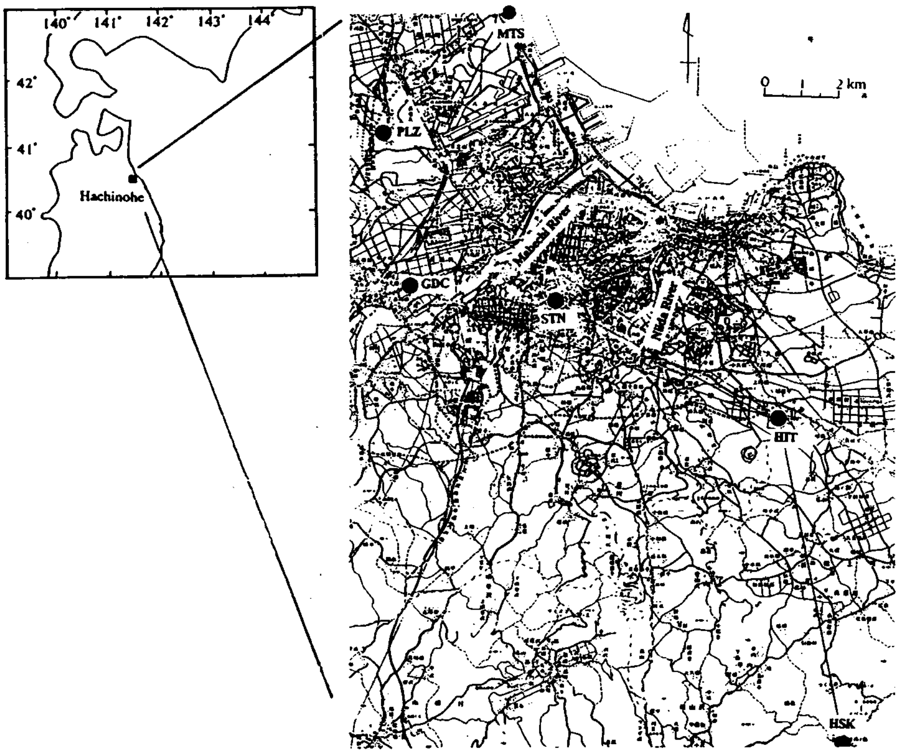

Figure 1 : Location of strong-motion sites used.

Six velocity-type strong motion seismographs stations were installed on bedrock and deep-soil deposit in and near Hachinohe city, where are HSK, HIT, STN, GDC, PLLZ, and MTS stations as shown in Fig.1. Each station consists of three components velocity-type seismometers and signals are digitized with 22-bit resolution at 100 samples/sec.HSK, HIT, STN, GDC stations have a communication port. Trigger condition is OR/AND combination of individual channels trigger and trigger level is different from each station depend on the ground noise level.

3. METHOD

To estimate the site response at observation site, the spectrum of P-wave, S-wave, and coida portion of the seismograms obtained from the site is divided by the spectrum of the corresponding portion of the seismogram from reference site for the same earthquake. For direct S-wave portion, we do not determine the accurate arrival time from the seismogram. We point out the S-wave arrival time duration time of S-waves by using the Husid-plot. We consider that the duration time of S-wave correspond to steep slope of the Husid-plot. The horizontal components of seismograms of

P-wave, S-wave, and coida portion were cosine-tapered (10 percent at each end of the time window) and were used to obtain Fourier spectra. We obtained a resultant of calculated spectra of two horizontal components of the seismograms.

The Fourier spectrum for observed seismogram represent at the station given by

$$Oi(f) = Sj(f) \bullet Pij(f) \bullet Rij(f)^{-1} \bullet Di(f) \quad (1),$$

where,

$Oi(f)$: Fourier spectrum of the observed seismogram at i-th station,

$Sj(f)$: source spectrum of j-th earthquake,

$Pij(f)$: path effect of j-th earthquake to i-th station,

$Rij(f)$: geometrical attenuation ,

$Di(f)$: i-th station site response.

The Fourier spectrum for the seismogram at the reference point is

$$Or(f) = Sj(f) \bullet Pjr(f) \bullet Rjr(f) \quad (2).$$

It is consider that the seismic wave is affected by geometrical and inelastic attenuation. The geometrical attenuation is independent on frequency. The path effect of $Pij(f)$ is replaced with the term of $Q(f)$;

$$Q(f) = \exp(-\pi f T / Qs) \quad (3),$$

where

T : S-wave travel time.

In computing the ratio equation (1) and (2), we can obtain the site response of observation sites.

The site response at the observation site are represented as

$$Di(f) = Oij / Or \bullet Rij / Rrj \bullet \exp(\pi f (Tij - Trj) / Q(f)) \quad (4)$$

where, Tij is travel time of S-wave from source to observation site, and Trj is that from source to reference point, respectively.

We assume that S-wave velocity from source to observation point is 3.5km/s, and $Q(f) = 120.9f$.

It is difficult to determine the S-wave arrival time from the seismogram, so we calculate the $Tij - Trj = (Rij - Rr) / Vs$, and replaced it, where Vs is S-wave velocity from source to observation point.

4. OBSERVATION AND RESULT

From April 1997 to July 1999, seismograms observed at HSK are 54events but the seismograms observed at all stations are 10 events. At GDC , STN and MTS station, the ordinary ground noise level is greater than 0.1cm/s in daytime , so the ground noise level is so high that setting to the condition of trigger level is very difficult. Example of a seismogram (December 23,1997, 41.4N, 142.1E, H=70.5km, M5.6) obtained at each station are shown in Fig. 2.

The information of the earthquakes was refereed to a prompt report on Internet from Institute of Seismology and Volcanology, Graduate School of Science, Hokkaido University. A remarkable contrast between these records: the seismogram at MTS, PLZ and GDC show conspicuous later phase with a duration longer than 100 seconds, whereas the seismogram at STN, HIT have large S wave-motions but can't see later phase and seismogram at HSK is simply composed of P and S wave motions. From these seismograms , we consider that the seismograms observed at MTS, PLZ and GDC are affected by the deep soil deposit , and STN and HIT reflect the shallow soil deposit, and HSK is on the bedrock. We used three time windows shown by bars signed P(P-wave), S (S-wave) and C (coda). Coda starts after twice

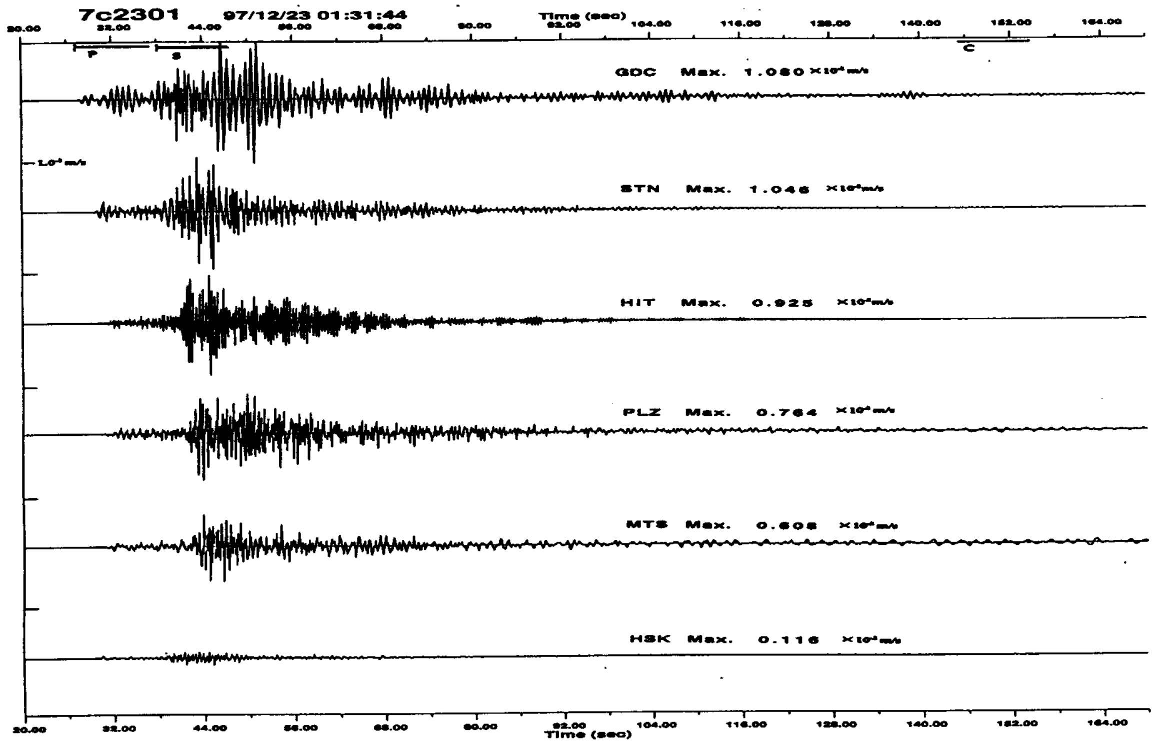

Figure 2 : Example of the seismograms obtained at each observation station.

of the S-wave travel time from the origin time. Duration time analyzed is 10.24sec(1024 points). A simultaneous observation of microtremors at the observation sites of HSK, HIT, STN, and GDC were made in 1999, June and July. The observation of long-period microtremors at the PLZ and MTS station was made at each observation site from time to time during the night. Appratus used a portable long-period seismometers, whose natural period is 8-second, and signals are digitized with 14-bit resolution at 50 samples/second. The data observed was computed Fourier spectrum by FFT method, and an analyzed data length is about 41 seconds (2048 points). We calculate the site response at each observation site corresponds to earthquakes by using the spectral ratio method, and we select the HSK station as a reference point.

4.1 HIT site

Average pectral ratio, spectrum of microtremors, and S-velocity structure at the HIT site are shown in Fig. 3.
Average pectral ratio of the P-wave, S-wave, and coda at HIT has a large peak from 2.5 to 2.8 Hz, which has good agreement with result of one dimensional multiple reflection theory of SH-wave calculated by model of the structure in Fig.3. And response of coda is lager than that of P- and S-wave. But the spectrum of microtremors has a peak of about 3 Hz.

4.2 STN site

This region suffered most from Far off Sanriku Earthquake of 1994. In this site, the bedrock locates about 100meter depths estimated from bore-hole logging. The average spectral ratio, spectrum of microtremors, at the site is shown in Fig. 4. Spectral ratio of P-wave, S-wave, and coda has two peaks of 1.3 Hz and about 4.0Hz, whose peak frequency of 1.3 Hz and 4.0 Hz is same as that of microtermors. We show the average spectral ratio of P-wave, S-wave, and coda and spectrum of microtremors.

4.3 GDC site

Average spectral ratio of GDC site to the HSK site has a large peak of about 1Hz and small one with frequency of 0.4 Hz. This small peak of 0.4 Hz may reflect deep soil deposit, whose bed-rock locate about 1000 meters depth. A spectrum of microtremors has small two peaks of about 1 Hz and from 2 to3Hz. The peak with about 1 Hz seems to reflect the response to the ground structure at the site, and peak frequency from 2 to 3 Hz in microtermors may reflect shallower one. The average spectral ratio and spectrum of microtremors are shown in Fig.5.

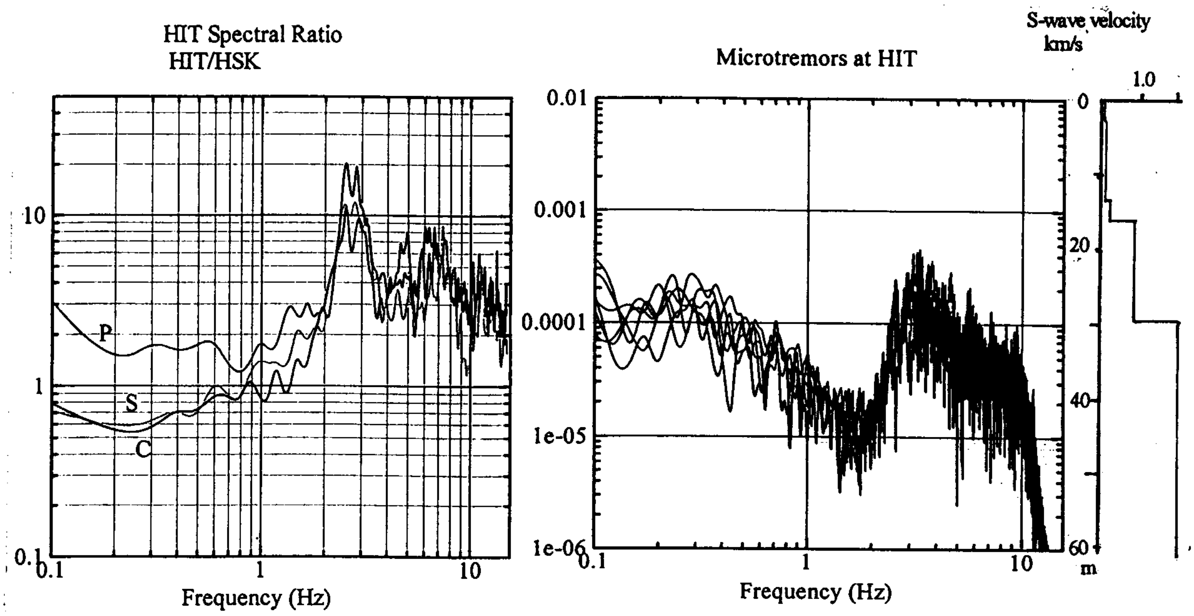

Figure 3 : Spectral ratio of the P-wave, S-wave, and coda and spectrum of microtermors and S-wave velocity structure at HIT site.
P : P-wave ,S: S-wave window ,C: coda windows respectively.
S-wave velocity structure was obtained by VSP(Vertical Seismic Profiling).

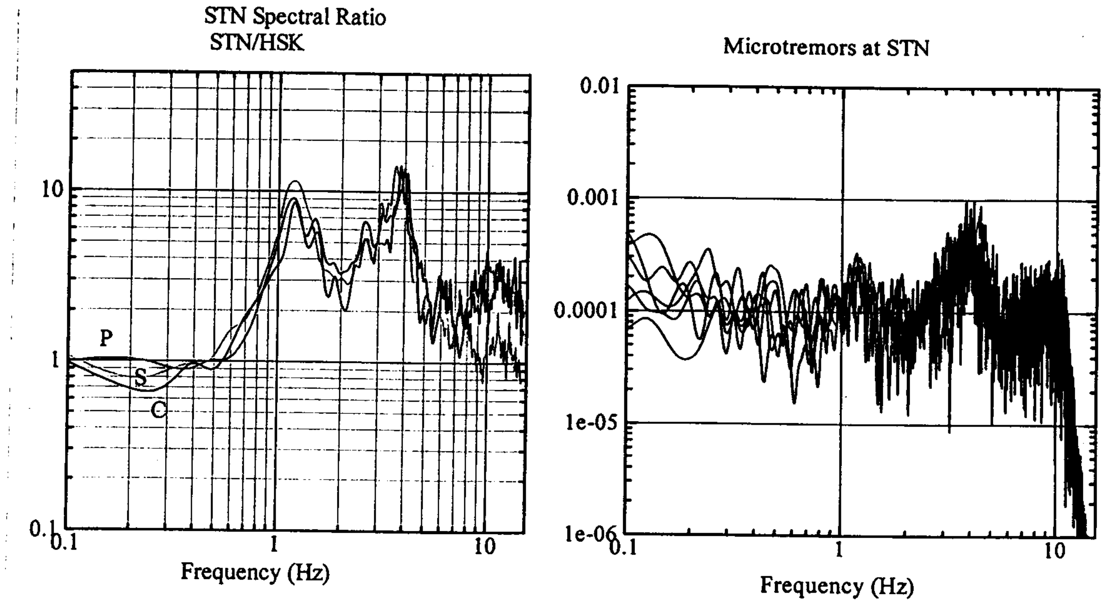

Figure 4: Spectral ratio of the P-wave, S-wave, and coda and spectrum of microtermors at STN site.
P : P-wave ,S: S-wave window ,C: coda windows respectively

4.4 MTS AND PLZ SITE

The site at MTS is on deep soil deposit whose depth to the bedrock is about 600 meters. The shape of spectral ratio of the P-wave, S-wave have no peak frequency, but that of coda has large and gentle peak frequency from 0.45 to 0.7 Hz. The On the other hand, spectrum of microtremors has a large peak frequency from 0.3Hz to 0.4Hz. This peak frequency of microtremors at MTS site is very stable in time, and has same peak frequency as that of Far off Sanriku Earthquake of 1994(M7.5, Δ =190km). The spectral ratio of the P-wave, S-wave, and coda and spectrum of microtremors and S-velocity structure are shown in Fig.6.

The spectral ratios of the P-wave, S-wave, and coda and spectrum at PLZ site are shown in Fig.7. As shown in Fig.7, the spectral ratio has two peaks of low and high frequencies whose are about 0.8 Hz and 3.3 Hz. On the other hand, spectrum of microtremors has two peaks of low and high frequencies whose are 0.25 Hz and 3.1 Hz and high frequency is same as that of spectral ratio but low one is the source spectrum of microtremors.

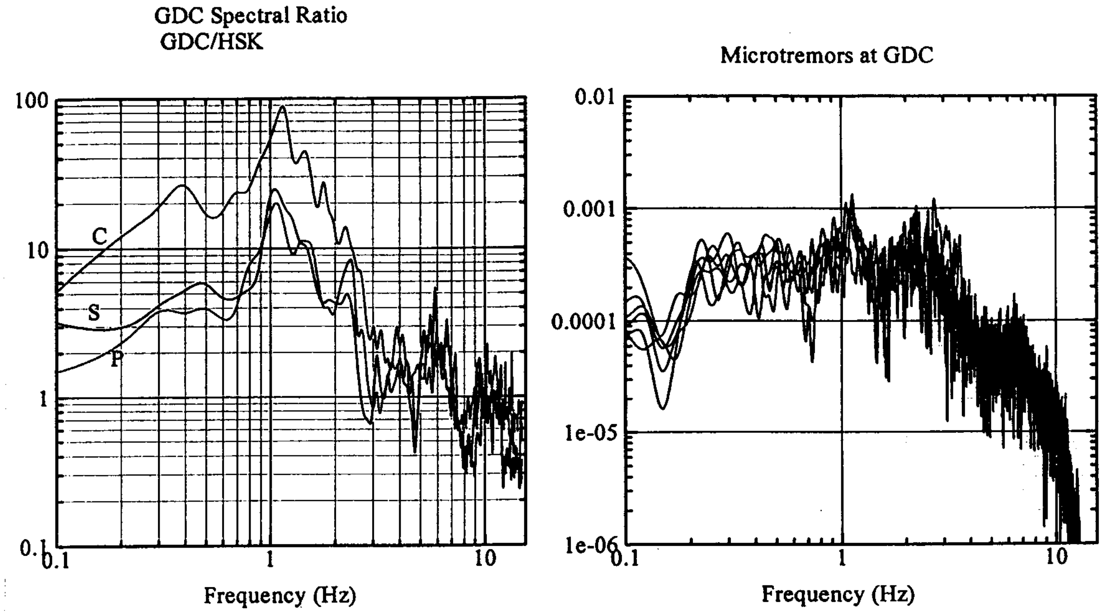

Figure 5: Spectral ratio of the P-wave, S-wave, and coda and spectrum of microtermors at GDC site.
P : P-wave, S: S-wave window ,C: coda windows respectively

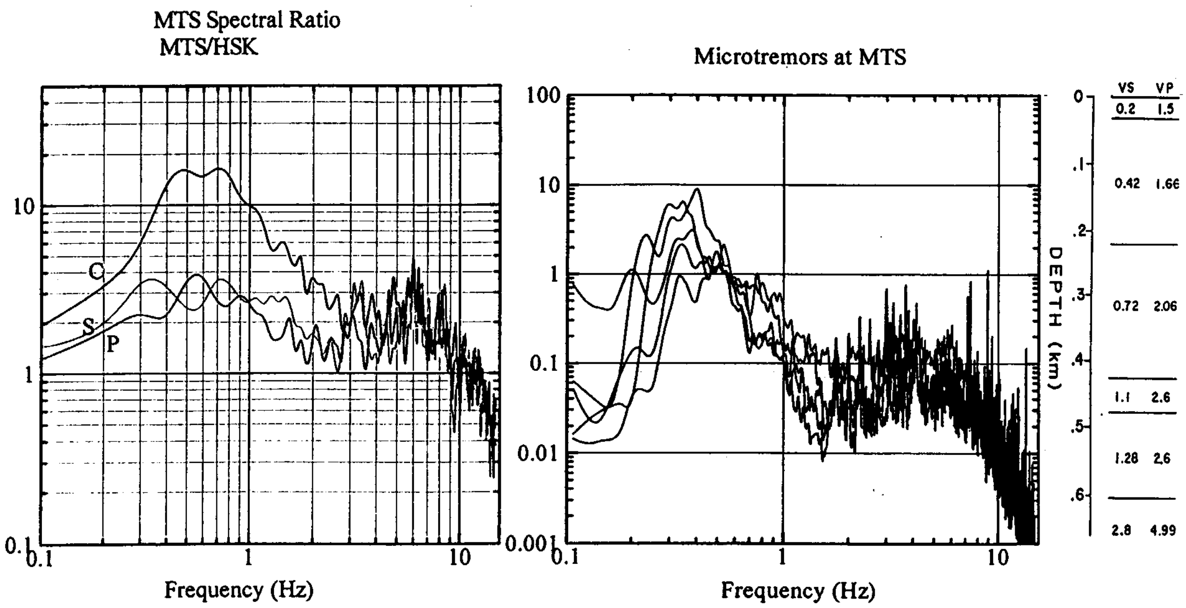

Figure 6: Spectral ratio of the P-wave, S-wave, and coda and spectrum of microtermors and S-wave velocity structure at MTS site. P : P-wave, S: S-wave ,C: coda windows respectively

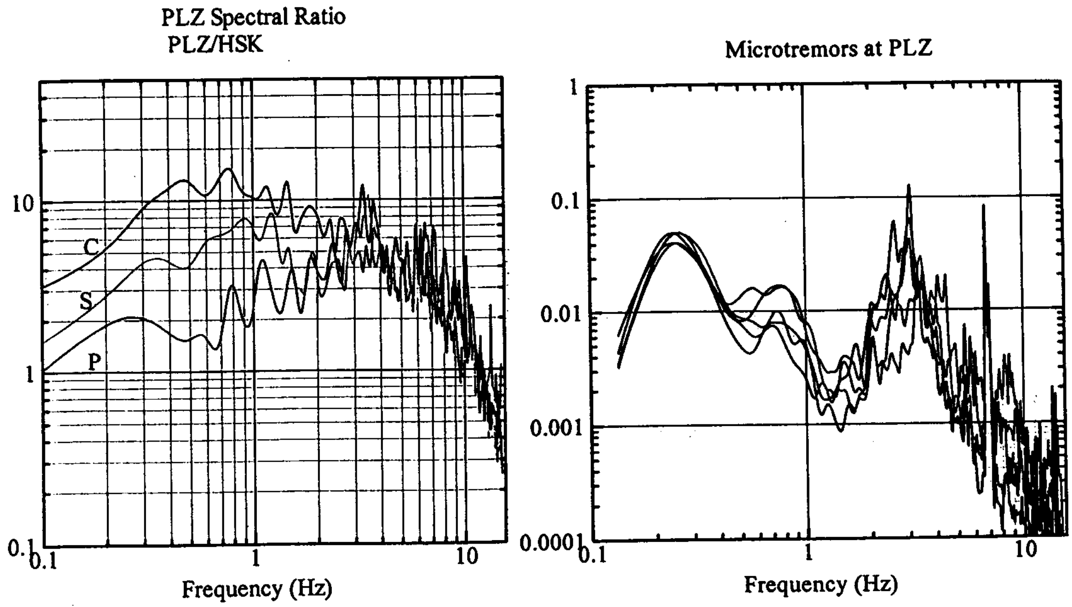

Figure 7: Spectral ratio of the P-wave, S-wave, and coda and spectrum of microtermors at PLZ site.
P : P-wave, S: S-wave ,C: coda windows respectively

5. CONCLUSION

The amplitude of spectral ratio of coda at the GDC, MTS, and PLZ are larger amplitude than that of P-wave and S-wave. On the other hand, at HIT and STN sites, the amplitude of coda are as same as that of P-wave and S-wave. Peak frequency of the spectral ratio of P-wave, S-wave and coda at STN, HIT, and GDC sites agree approximately with that of microtremors. The difference of P-wave, S-wave, and coda from microtremors at MTS site may be due to the maginitude of earthquake analyzed, or SN ratio of the records. PLZ sites has common peak frequency of 3.1Hz, this frequency reflrect shallow ground structure. We consider that there seems to be high velocity contrast between bed-rock and subsoil at HIT,STN and GDC sites. The predominant period of microtremors on soil deposit does not necessarily always show a correspond to that of seismic waves. If we observe the microtremors at the site where velocity contrast between soil deposit and bedrock, then the strong period predominancy is observed. So the microtrmors is one of a useful method to estimate site response. To make comparison between the spectrum of microtremors and that of seismic waves, statistical treatment is one of advantageous methods.

6. REFERENCES

Castro .R.R, J.G. Anderson, and S.K. Singh,1990,Site Response, Attenuation and source spectra of S waves along the Guerrero,Mexico, subduction zone, Bull. Seis. Soc. Am., 80,1481-1503.

Castro .R.R.,L.Munguia, and J.N.Brune,1995, Source Spectra and Site Response from P and S waves of local earthquake in the Oaxaca, Mexico, subduction zone, Bull. Seis. Soc. Am., 85,923-936.

Lermo.J. and Francisco J. Chaves-Gracia,1994, Are Microtremors useful in site response evaluation?, Bull, Seism. Soc. Am., 84, 1350-1364.

Margheriti.L. , L. Wennerberg, and J. Boatwrigh,1994, A comparison of coda and S-wave spectral ratio as estimates of site response in the Southern San Francisco Bay area, Bull, Seism., Soc. Am.84,1815- 1825.

Nakamura ,Y. 1989, A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, QR of RTRI 30,25-33.

Sasatani ,S. ,M. Ikeda ,and N. Sakajiri,1992, et al. 1992, A study of site effects by mean of strong-motion seismograms from near-by, intermediate-depth earthquakes, Jour. Phys. Earth , 40, 85-98.

Sato,S., H.Kaease, S. Matsushima, 1998, Differences of Empirical Site Characteristics Obtained from Microtremors, S-wave, P-wave, and coda, and their Theoretical Interpretation, Zisin 2, 51,291-318 (Japanese with English abstract).

Takemura ,M., K. Kato, and T. Ikeura et. al. , 1991, Site amplification of S-waves from Strong motion records in special relation of surface geology, Jour. Phys. Earth, 39, 537-552.

Zao,B., M.Horike, Y.Takeuchi, H,Kawase, 1997, Comparison of Site-specific Response Characteristics Inferred from Seismic Motions and Microtremors, Jisin2, 50, 67-87 (Japanese with English abstract).