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INVESTIGATION ON APPLICABILITY OF H/V SPECTRUM OBTAINED FROM MICROTREMORS TO SEISMIC MICROZONING STUDY

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ABSTRACT

Recently, inland type earthquake at Japan capital region (Kanto) is predicted and several disaster mitigation measures are considered. Investigation of site effect due to surface soil structure is basically important for the estimation of damage distribution. H/V spectral ratios obtained from microtremors are considered to be the fastest and cheapest estimation method for soft ground layers site effects, however some questions about their application and interpretation remained to be answered. In this paper, We would like to present the applicability of microtremors characteristics by comparing the H/V characteristics between microtremors and seismic motions and SH wave transfer function obtained or calculated at 150 sites from a dense seismic station network in Yokohama City. We could confirm that the H/V spectra of microtremors are a very reliable estimation method for site response when the soil characteristics of soft deposits are in good contrast with the base soils.

Introduction

Recent disaster prediction studies estimates a significantly large earthquake could be occurred under Japan capital region. Studies based on the response of the surface ground structure to earthquake motion as well as detailed wave propagation have become important topic with respect to fundamental earthquake disaster prevention works. The conventional methods of numerous borehole log data collection, the seismic intensity distribution and earthquake dynamic characteristic investigations, are desirable, but, expense and time make them very difficult tasks regarding to social and natural limitations. Among different methods, microtremors observation methods are proven to be time and cost effective, however some questions about their application and interpretation remained to be answered. Therefore it is necessary to try to utilize the application of microtremors as an evaluation method with high precision.

A dense strong motion observation network put in service by Yokohama City. 150 observation stations scattered all over the city. After any observed event the intensity distribution map and other data will be announced to public via internet and mass media. Digitized geological (Yokohama City 2001), geomorphologic and ground amplification data are used for the map preparations. The detailed observed accelerograms are also available on request from the city of Yokohama.

Different applications of microtremors have been put on test by many researchers in Yokohama City. Ohmachi and others (1994) observed microtremors in public elementary schools; they pointed out the

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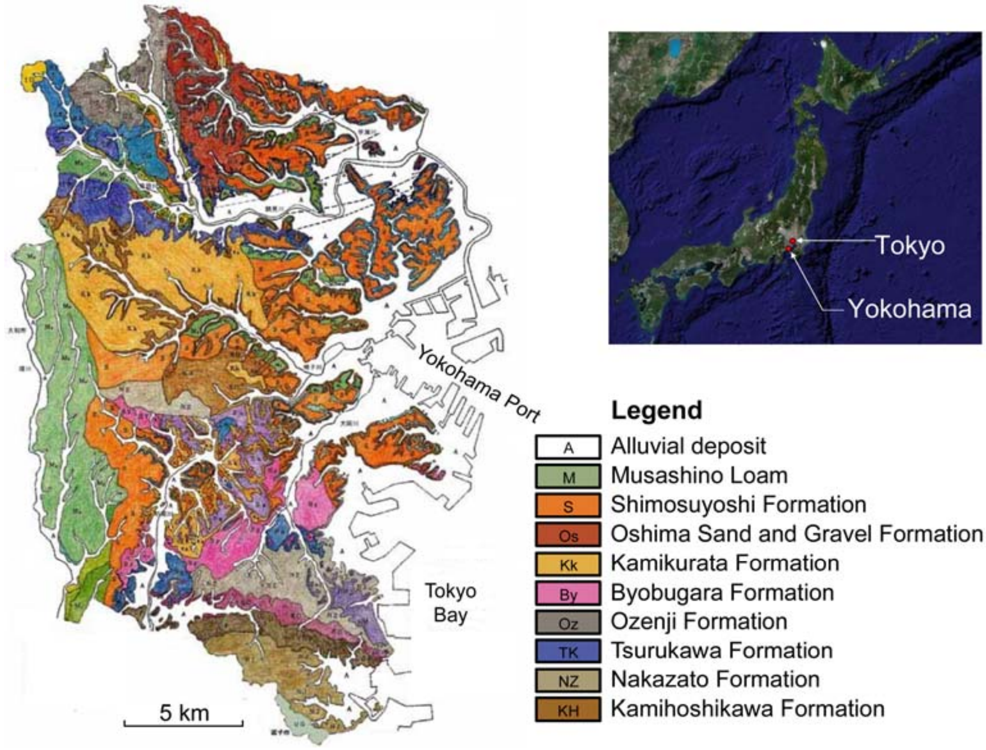


Figure 1. Geological Map of Yokohama City (Sugimoto and Oka 1996).

possibilities to estimate ground structure characteristics from H/V spectrum. Rodriguez and others (2003) proposed a ground classification method by comparing the features of the H/V spectra of earthquake record and the microtremors observed at similar locations.

In this research we obtained earthquake records for all 150 stations of the network of Yokohama city and analyzed H/V spectral ratio from them. Then we recorded the microtremors at identical locations and compared their H/V spectra with earthquake results. In addition, the ground geology model of each observation station was used to calculate one dimensional transfer function to a vertical incident SH wave.

We examined the usefulness of the H/V spectral ratio as a substitution for strong motion records by considering the correlation between their characteristics observed in Yokohama city.

Geological and Topographical Features of Yokohama City

Geological features of Yokohama City are shown in Fig.1. Hilly terrace in the west parts consists of the firm Kanto loam and their alluviums are carried by rivers toward the low lands on east where there form very soft alluvial deposits of even 50m depth. Also reclaimed lands are distributed widely in coastal regions along the eastern seashores. The alluvial sites could amplify the seismic waves in many areas where we are to study in this paper. However we should not forget the possibility of liquefaction in lowland areas.

Microtremors, Earthquakes and Transfer Functions

Microtremors

Microtremors were observed at 150 points as the same locations as the Yokohama city strong motion seismograph network stations, shown in Fig. 2. The measurements had been done during three years

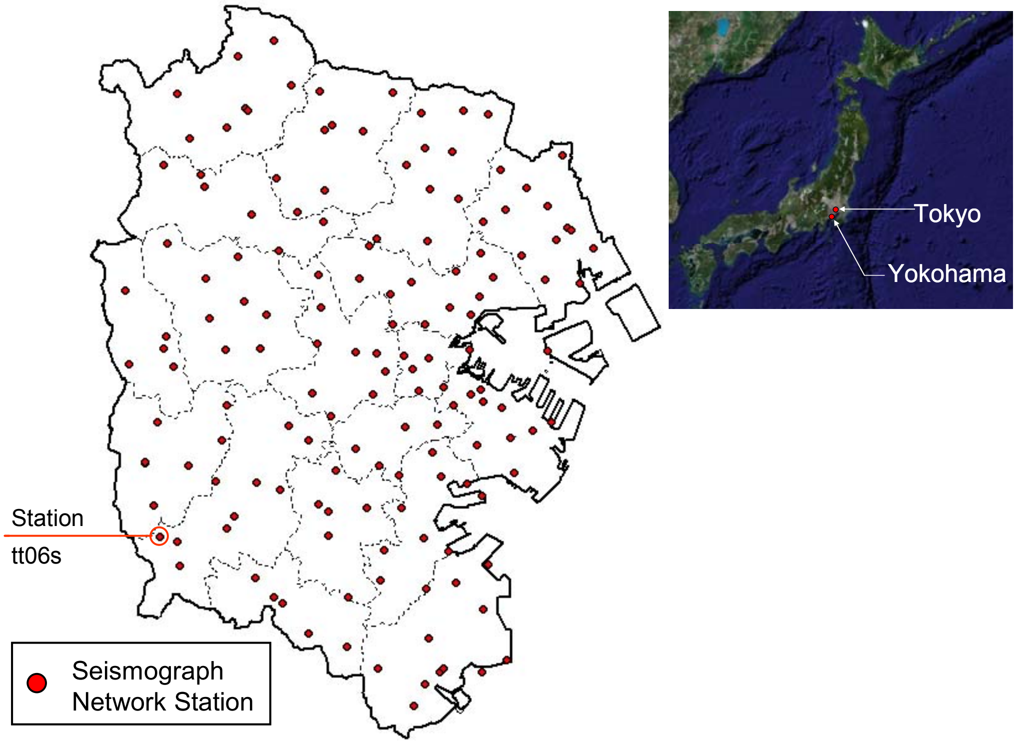


Figure 2. Distribution of Yokohama city strong motion seismograph network stations.

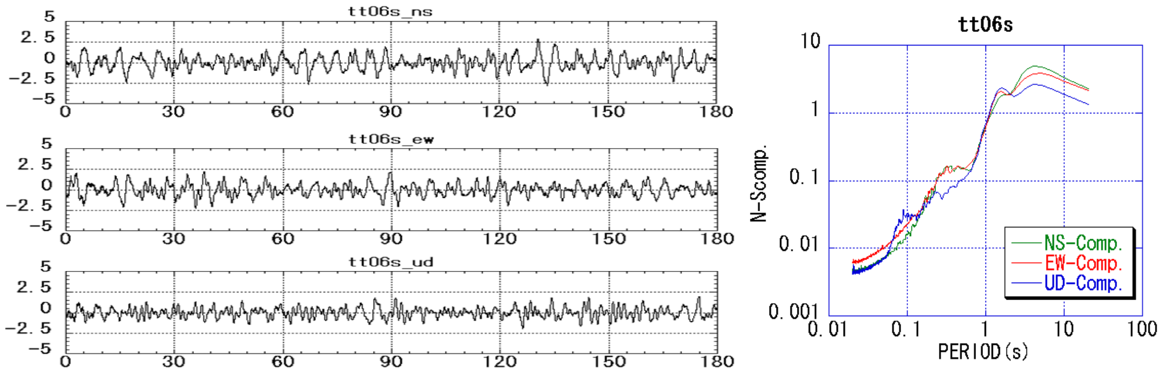


Figure 3. An example of waveforms and Fourier spectra obtained from microtremors observation at station tt06.

from 2001 to 2004. 12 recordings in Kanagawa ward during 2001, 111 in 2003 and the rest of the recordings (27) were made in 2004.

Tokyo Sokushin "SPC-51K" instruments were used for microtremors recordings. The 3-component velocity-meters installed within 5-meter distance from seismograph's position. We recorded along three principle directions NS, EW and Vertical (UD). Duration of observations set to 180 seconds with sampling frequency of 100Hz. Fig. 3 shows an example of waveforms and Fourier spectra obtained from microtremors observation at station tt06. The Fourier spectra were computed with FFT method and then smoothed by Parzen window with a 0.3Hz bandwidth. The horizontal component calculated by taking the geometrical mean of two horizontal components and then divided by vertical component.

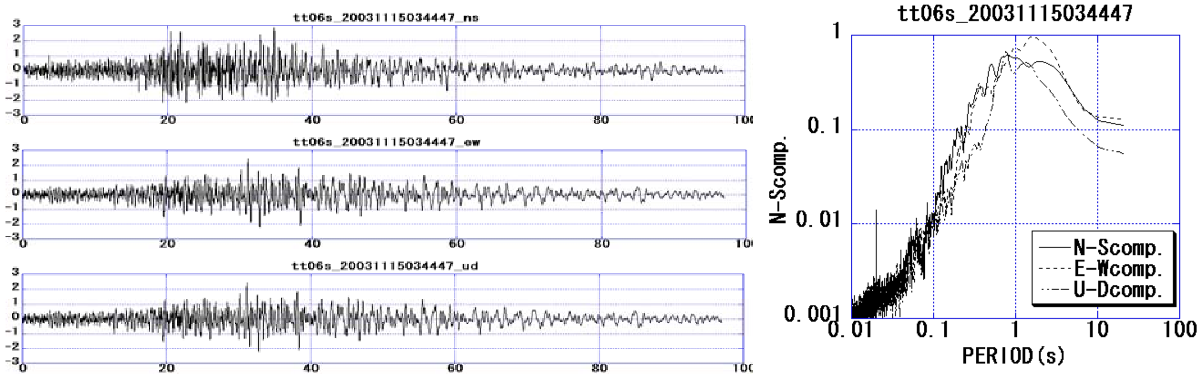


Figure 4. An example of waveforms and Fourier spectra obtained from earthquake observation at station tt06.

Earthquakes

Digitized data of 8 earthquakes observed by Yokohama city seismograph network are listed in table 1. These data obtained from the ones released on Internet. The earthquakes, which are used in this study, obtained from the events between January 2001 and June 2006. The earthquakes have large magnitudes (more than M5) and the distances from Yokohama city are far enough to provide coda waves to be compared with microtremors.

Coda waves are thought to consist relatively of surface waves due to multiple refractions and distracted propagations. On analysis of earthquake records, we chose the coda parts of three components. Fig. 4 shows an example of waveforms and Fourier spectra obtained from earthquake observation at station tt06. The coda waves assumed to be existed from the moment that the accumulative earthquake energy riches the 80% mark therefore we calculated the accumulative energy of NS component and then chose a 20.48 second of coda waves. The Fourier spectra were computed with FFT method and then smoothed by Parzen window with a 0.3Hz bandwidth. Similar to the procedure for microtremors the horizontal component calculated by geometrical mean of NS and EW components to be used for H/V calculations.

For each of 150 stations in Yokohama city, we calculated the microtremors H/V spectral ratios from as many undisturbed segments of 20.48 seconds from total of 180 seconds of recordings and obtained their average to delete the effect of transient disturbances. We also calculated the average of H/V spectral ratios observed from 8 coda wave records to reduce the effect of possible unique cases. Thereafter the two average spectral ratios are compared together. A sample of such comparison for station tt06 is shown in Fig. 5.

Table 1. Basic information concerned to 8 earthquakes used in this study.

No	Date / Time	Latitude / Longitude	Dist.[1] (km)	Depth (km)	Magnitude	Name
1	2002/02/12 / 22:44	N36°59’ / E141°09’	230	48	M5.5	North Eastern Ibaraki prefecture
2	2003/05/12 / 00:57	N36°27’ / E140°09’	130	47	M5.2	Southern Ibaraki prefecture
3	2003/05/17 / 23:33	N36°13’ / E141°05’	165	47	M5.1	North Eastern Ibaraki prefecture
4	2003/05/26 / 18:24	N39°20’ / E142°08’	495	71	M7.0	Northern Miyagi prefecture
5	2003/09/20 / 12:55	N35°22’ / E140°30’	95	70	M5.8	Southern Chiba prefecture
6	2003/10/15 / 16:30	N36°01’ / E140°05’	80	74	M5.1	Northern Chiba prefecture
7	2003/10/31 / 10:06	N38°23’ / E143°10’	465	33	M6.8	Eastern Miyagi prefecture
8	2003/11/15 / 03:44	N36°43’ / E141°17’	217	48	M5.8	Eastern Ibaraki prefecture

[1] Distances are calculated from station tt06s

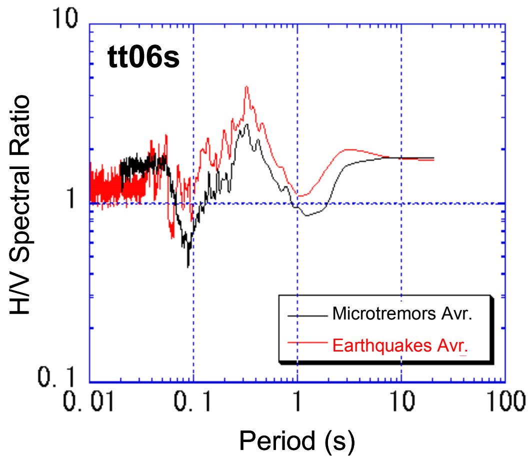


Figure 5. A sample of average H/V spectral ratios for Microtremors and earthquakes (station tt06).

Theoretical Analysis of Surface Ground Vibration Characteristics

Yokohama City provided the boring data and the P-S logging results for all 150 stations such as detailed soil layers thickness (h_i), density (ρ_i), P and shear wave velocities (Vp_i, Vs_i). We used this information and built ground structure model for all stations. In these models we assumed 10% damping for soil layers and considered the engineering base would be a layer with Vs greater than 700 m/s. One dimensional transfer function calculated for the structure model at each station.

The equivalent shear wave velocity and density for a total thickness is calculated by Eqs. 1 to 3.

$$H = \sum h_i \tag{1}$$

$$Vs = \sum Vs_i h_i / H \tag{2}$$

$$\rho = \sum \rho_i h_i / H \tag{3}$$

Where Vs and ρ are the equivalent values for a layer with thickness H (total thickness of soft layers), the contrast between the surface soil vibration characteristics and the base soil will be calculated by Eq. 4

$$\text{Contrast ratio} = (\rho Vs)_{Base} / (\rho Vs)_{Surface} \tag{4}$$

Comparison Between Earthquakes And Microtremors

We chose three main features in H/V spectral ratios for comparison.

1. The predominant period (T),
2. The corresponding spectral ratios (R) and
3. The spectrum curve’s area between the periods of 0.1 and 2.5 second interval (S).

Figs. 6 to 8 respectively shows these features in one-to-one charts to see if there are any correlations between microtremors and coda waves. Relatively good correlations are found for features like predominant periods and the corresponding spectral ratios (T and R), however the spectrum curve’s area (S) does not show excessively satisfactory correlation characteristics

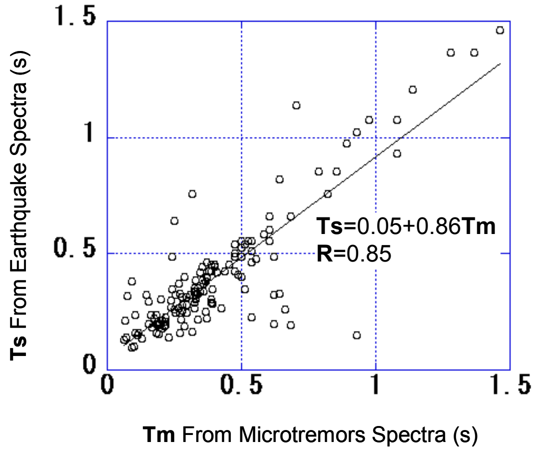


Figure 6. Comparison of predominant period values between microtremors (Tm) and seismic motion observation records (Ts).

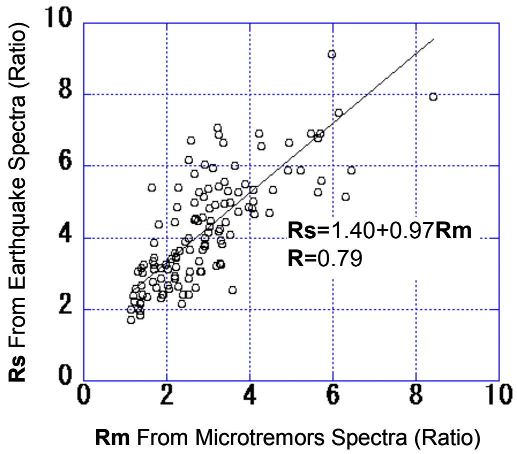


Figure 7. Comparison of amplification factor value between microtremors (**Rm**) and seismic motion observation records (**Rs**).

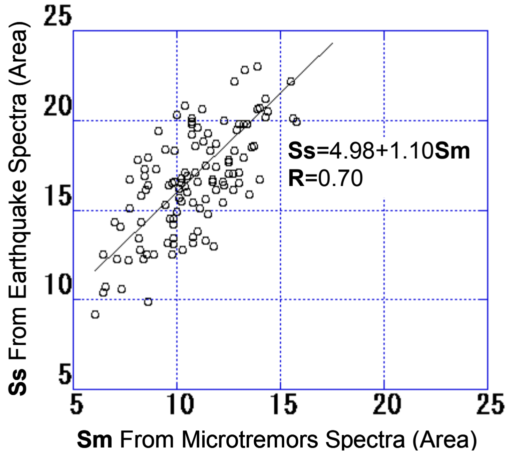
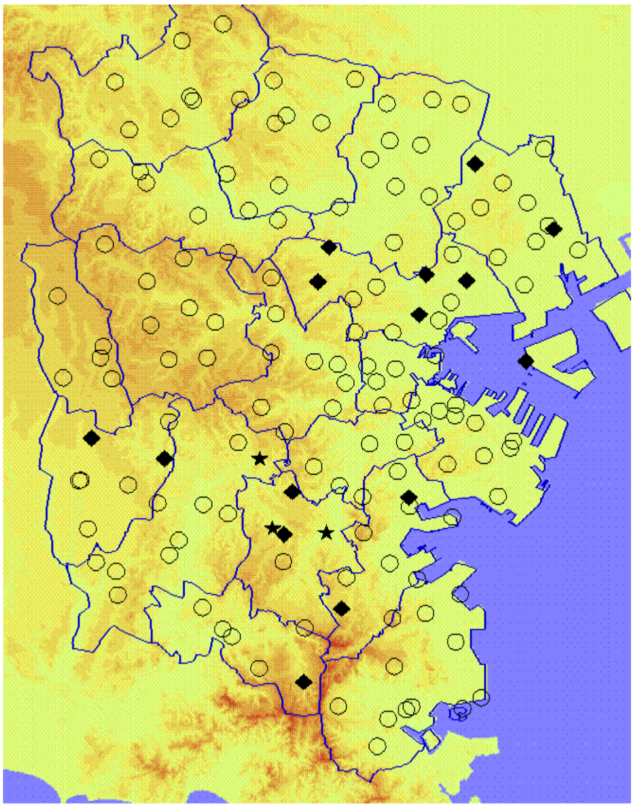


Figure 8. Comparison of spectral area value between microtremors (**Sm**) and seismic motion observation records (**Ss**).



(Circles) correlation over 90%, (Diamonds) correlation less than 90% and (Stars) No data.

Figure 9. H/V spectral Feature comparison between microtremors and coda waves. A spatial demonstration.

We established a criterion to choose acceptable correlation factor to apply to these three features. As a general rule of deviation if two out of the three features have a misfit less than 10 percent then we consider them agreeable otherwise they do not agree. Using the mentioned criteria between the three features; T, R and S, the results are summarized in Fig. 9. The statistics shows 132 stations out of 147, about 88 percent of the locations, have correlation over 90% in at least two features (Circles) and the other 15 stations shown correlations less than 90% (Diamonds). We could not obtain coda waves for 3 stations (Stars), which were excluded from our statistics.

Comparison Between Earthquake and Analytical Transfer Function

We compared earthquakes average H/V spectra and calculated transfer functions for 147 out of 150 stations in Yokohama city. Fig. 10 shows two examples of these evaluations. Fig. 10(a) shows an example, which the values of predominant period of both agrees (site as02). On the contrary in Fig. 10(b), the predominant period peaks in two spectra (site iz05) are not match with each other. There exist cases where we observed multiple peaks in H/V spectral ratio of the coda section of earthquake record, due to the effect of periodic component of the higher mode S wave components. In such cases we obtained the peak with longest period value. Fig. 11 compares the predominant period values extracted from one-dimensional transfer functions with the ones obtained from earthquake H/V average spectra. 113 stations out of 147 (about 78%) show very good consistency between the observed and calculated predominant periods.

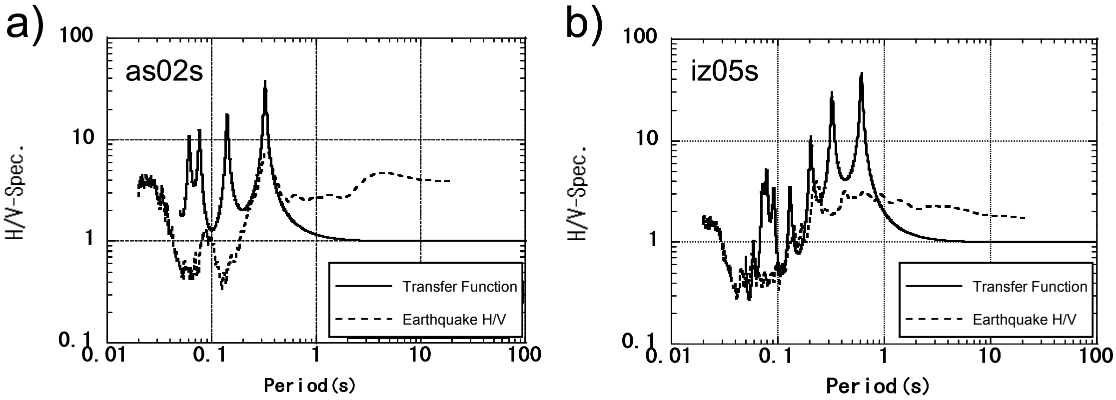


Figure10. Examples of agreement between H/V spectral characteristics obtained from seismic motion record and transfer function calculated by theoretical 1-D response analysis. [a) Up: Good agreement (Site: as02s) and b) Down: Bad agreement (Site: iz05s)].

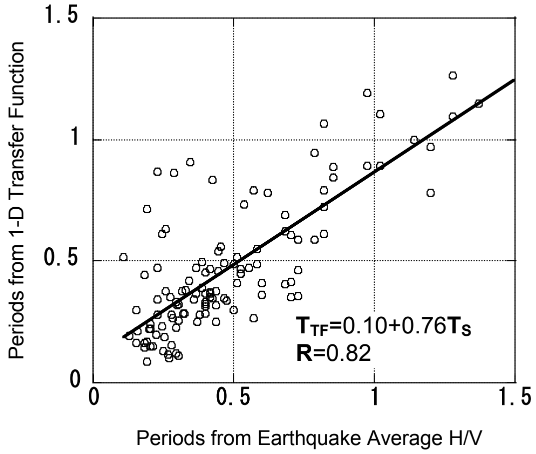


Figure 11. Comparison of predominant period values (T) between H/V spectral characteristics obtained from seismic motion record and transfer function calculated by theoretical 1-D response analysis.

Classification of Ground Condition Based on H/V Spectral ratio

By comparison between average H/V spectra of microtremors and strong motion's coda waves with boring logs we divided the ground structure to four categories A, B, C and D (Table 2). Consequently, as shown in Fig. 12, we found out that at the observation points where corresponded characteristic of H/V spectral ratio are comparatively consistent (over 90%) were among those stations where the overlaying soft soil layers and the base layer have a clear contrast calculated by Eq. 4, (Soil classes A and C). The observation points where we were not able to find good consistency (less than 80%) were mainly seen in soils with complicated multi-layered structure where a clear contrast boundary could not be placed between the base soil and surface (Soil classes B and D).

Table 2. Classification of soil structure by geotechnical information and statistics of the consistency between microtremors and seismic motions H/V spectra in Yokohama City.

Category	Total Pairs of spectra	Consistent Pairs of spectra	
		(Counts)	(%)
A: Shallow Soil Deposits, Contrast ratio ≥ 3	86	79	92
B: Shallow Soil Deposits, Contrast ratio ≤ 3	9	7	79
C: Deep Soil Deposits, Contrast ratio ≥ 3	30	30	100
D: Deep Soil Deposits, Contrast ratio ≤ 3	25	19	76

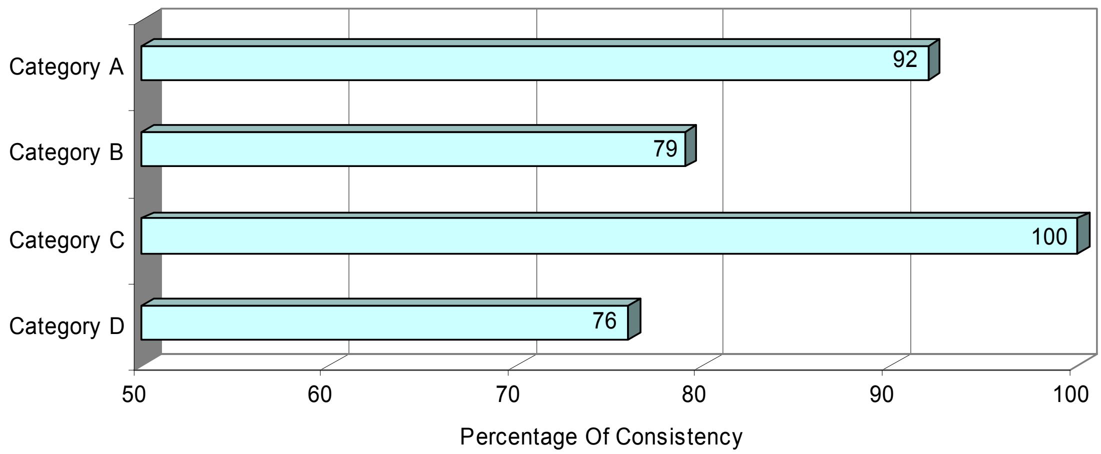


Figure 12. Percentage of the consistency between microtremors and seismic motions H/V spectra in Yokohama City.

Summary and Conclusions

In this research, we investigated the limits of application of microtremors H/V spectral ratio by comparing between observed microtremors and the coda waves obtained from strong earthquake records at Yokohama city accelerograph network. As a result, we could verify and compare three characteristic features of H/V spectral ratios obtained from both methods in Yokohama city. Predominant periods (T) and amplification factors (R) obtained from microtremors H/V spectral ratios correlated well with corresponding H/V spectral ratios of earthquakes. However the area under the spectrum between period ranges of 0.1 to 2.5 seconds had low correlation.

We also compared the predominant period values extracted from one-dimensional transfer functions with the ones obtained from earthquake H/V average spectra. About 78% of data show very good consistency between the observed and calculated predominant periods.

In addition by comparison between average H/V spectra of microtremors and strong motion's coda waves with boring logs we divided the ground structure to four categories. Consequently, we found out that at the observation points where the overlaying soft soil layers and the base layer have a clear contrast corresponded characteristic of H/V spectral ratio are comparatively consistent and the observation points where a clear contrast boundary could not be placed we were not able to find good consistency were mainly seen in soils with complicated multi-layered structure between the base soil and surface. This result would be recognized as an application limit for H/V of microtremors since in absence of any complementary soil data the results could not be interpreted correctly.

Acknowledgements

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