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# Use of Microtremors for the Estimation of Ground Vibration Characteristics

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SYNOPSIS Short-period microtremor array observation is conducted at five sites in the Tokyo Metropolitan area of Japan. The Fourier spectra of horizontal and vertical components show variations in time, but their ratio is stable for different time instants. The characteristics of the amplitude ratio are similar to that of Rayleigh wave and the period corresponding to the peak ratio correspond to the predominant period of the sites for shear wave propagation. A parametric study for two-layered models reveals that the peaks for Rayleigh wave and shear wave are close for the ground having large impedance ratio. The F-K spectrum analysis using vertical components obtained the phase velocity close to the dispersion curve for the Rayleigh wave.

## INTRODUCTION

Microtremor contains information about the characteristics of ground that can be used for the estimation of ground vibration during an earthquake. Wave propagation mechanism of microtremor and its relation with ground vibration characteristics are studied from the beginning of microtremor studies (Kanai et al., 1954; Aki, 1957). Meanwhile practical application of microtremor in the field of engineering has advanced tremendously. One of the powerful and simplest application of microtremor observation is in seismic micro-zoning.

From the array observation of microtremor of period greater than 1 s, Rayleigh-wave and Love-wave originating from natural sources, such as sea wave, variation of air and wind pressure, can be recognized. On the other hand short-period microtremor of period less than 1 s is thought to be generated by artificial noises such as traffic vehicles, industrial plants, household appliances etc. Some researchers (Sato et al., 1991; Tokimatsu and Miyadera, 1992) have showed that microtremors are mainly composed of fundamental mode of Rayleigh-wave. Nakamura (1989) has showed that short-period microtremor bears resemblance to S-wave characteristics. Tamura et al. (1993) have showed that predominant period of ground is dominated by Love-wave. However, the real generation and nature of microtermors have not yet been established.

In this study, microtremor array observations are conducted at five sites in the Tokyo Metropolitan area of Japan, where soil-structure are known. The objective of this study is to investigate the nature of microtremor and ground vibration characteristics.

## MICROTREMOR OBSERVATIONS

Short-period microtremors are observed at five sites within the facilities of Tokyo Gas Co. Ltd., namely, Fujisawa, Kanagawa Prefecture; Kodaira, Tokyo Metropolis; Soka, Saitama Prefecture; Sodegaura and Yotsukaido, Chiba Prefecture. These sites, which have borehole seismometers, are located in the outer edge of the gas service area (Fig. 1). The radio-transmitted records from these stations are used to determine the magnitude and focus of an earthquake within a few minutes after the occurrence of an earthquake (Yamazaki et al., 1994). Microtremors are observed using arrays at Kodaira, Sodegaura and Soka and one-point measurements are conducted at Fujisawa and Yotsukaido. Among these sites, Fujisawa, Kodaira and Soka are residential areas, Yotsukaido is an agricultural area and Sodegaura is an industrial area. For these sites geological investigations (boring and PS-logging) exist. Figure 2 shows S-wave and P-wave velocity profiles at the five sites.

The instrument used for the microtremor measurement is SPC-35T (Tokyo Sokushin Co.). The obtained velocity records by the sensors are highpass-filtered and amplified (amplifier: 8 channels) and then converted to digital recording using a 16 bits AD converter for storage in the hard disk of a personal computer. For velocity, sensitivity of the instrument is flat for period less than about 1 s. The observed arrays are pentagonal in shape with 3 sensors at the center: one vertical (UD) and two horizontal (NS, EW) and 5 vertical sensors (UD) arranged at five corner points of the pentagon having radius of 20 m. Microtremor observations are recorded for 2 minutes per hour at every hour for 24 hours at each site by using the built-in clock of the personal computer. Sampling frequency of 100 Hz has been used.

## FOURIER SPECTRUM OF HORIZONTAL AND VERTICAL MOTION

Obtained velocity records were converted from time domain to frequency domain to get the Fourier spectrum and it has been smoothed by using a Parzen window of bandwidth 0.4 Hz. Instead of using all the observed time records 6 time instants at each 4 hours are selected for investigation.

Figure 3(a) shows the vertical and horizontal Fourier spectra of microtremors observed at Kodaira. The horizontal motion in the afternoon (8h, 12h and 16h) has a wide peak between 0.2 to 0.4 s and in the night (20h, 24h and 4h), it has two peaks around 0.2 s and around 0.4 s. For

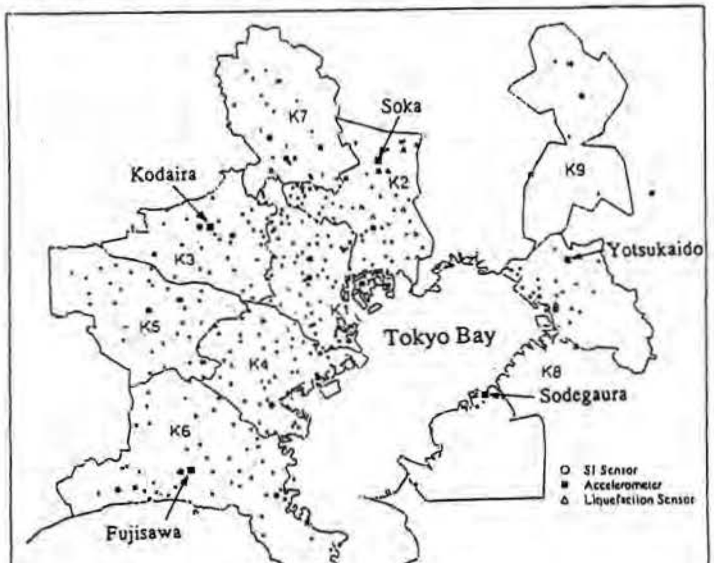
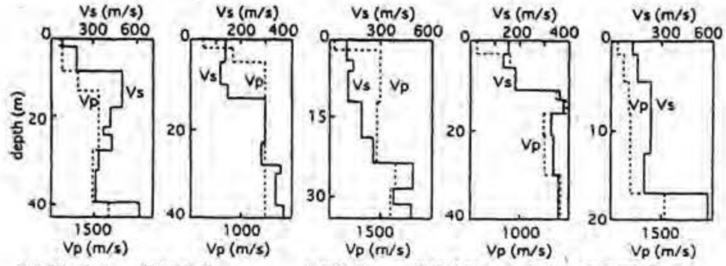



Fig. 1 Earthquake monitors in the service area of Tokyo Gas.



(a) Kodaira (b) Sodegaura (c) Soka (d) Yotsukaido (e) Fujisawa

Fig. 2 Underground structures of the five sites.

vertical motion, there are two peaks one around 0.1 s and another around 0.4 s. The peak around 0.4 s is comparatively more stable than the peak around 0.1 s within a day.

Figure 3(b) shows the vertical and horizontal Fourier spectra of microtremors observed at Sodegaura. Both spectra are almost stable during a day. Several sharp peaks for all the six time instants can be observed for the both spectra especially a peak around 0.1 s, where amplitude level is high. This may be due to vibration of machineries in a nearby machine room. There is another almost stable peak around 0.4 s for horizontal Fourier spectrum but no other peak can be observed for vertical Fourier spectrum.

The Fourier spectra (Fig. 3(c)) at Soka are similar to the spectra at Sodegaura, where the change of amplitude level of the spectra at different time instants of a day is comparatively small. Again, for other sites such as for Yotsukaido (Fig. 3(d)) and Fujisawa (Fig. 3(e)) the Fourier spectra are similar to the spectra at Kodaira, where the change of amplitude level of the spectra at different time instants of a day is comparatively large.

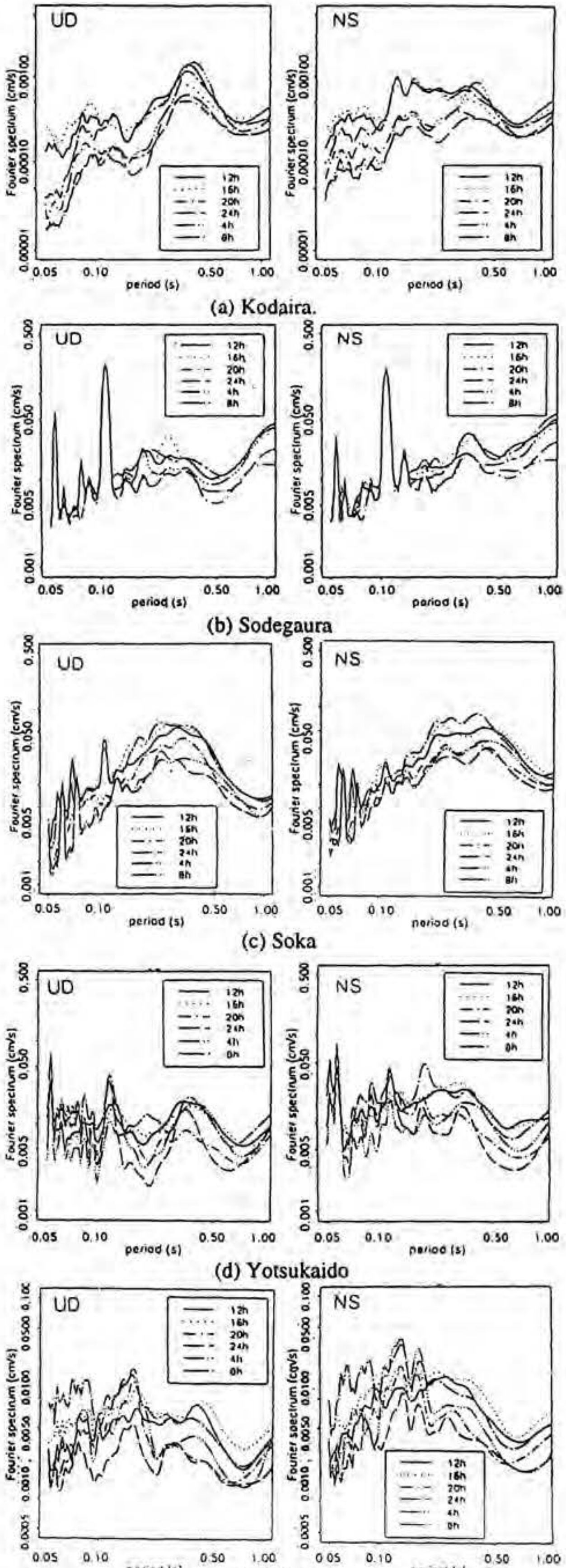
## AMPLITUDE RATIO OF HORIZONTAL AND VERTICAL FOURIER SPECTRA

In Fig. 4, amplitude ratios (NS/UD and EW/UD) of the Fourier spectra of two horizontal components for six time instants are shown for the five sites. The characteristics of the period for the amplitude ratios of microtremor are different from the characteristics of the period for Fourier spectrum. Although the Fourier spectra at Kodaira, Yotsukaido and Fujisawa are less stable, their amplitude ratios at different time instants of a day are comparatively stable. Especially the Fourier spectra for Sodegaura show a peak around 0.1 s probably due to the machine vibration but for the amplitude ratio that peak can not be observed. From these facts, it can be concluded that the amplitude ratio is less influenced by the source of vibration than the Fourier spectrum at any direction and may reflect the particular characteristics of the ground.

From the existing borelogs and PS-logging, soil model at each site is established for theoretical analysis. Transfer function of the S-wave (the surface motion versus the incidental motion at about -40 m) and amplitude ratio $(\dot{u}/\dot{w})$ for the fundamental mode of Rayleigh-wave are calculated at the sites using those soil models. For the calculation of transfer function of S-wave a damping ratio of 2% has been used. Figure 5 shows the transfer function of S-wave, amplitude ratios of Rayleigh-wave and microtremor. During comparison with the theoretical curves the amplitude ratio of microtremor used is the average of several fixed time windows. The pattern of three curves, i.e., two theoretical and one observed at each site closely resembles each other. Especially in between the amplitude ratios of Rayleigh-wave and microtremor observation, the period at which the Rayleigh-wave amplitude ratio either suddenly drops or peaks, microtremor amplitude ratio closely resembles it. Again at Fujisawa, transfer function for S-wave does not closely resembles the other two amplitude ratios but the tendency is similar.

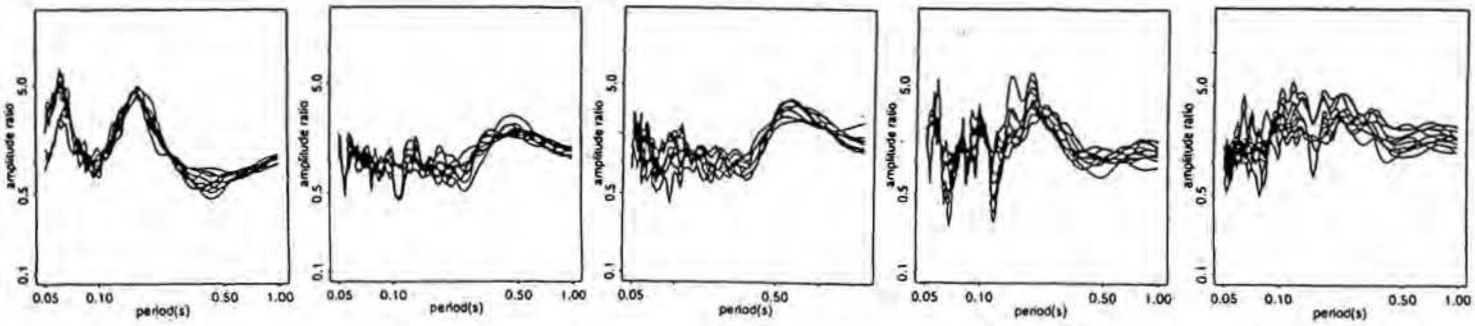
### Two layer soil parametric model

To investigate the reason behind the similarity between the period corresponding to the peak amplitude ratio of the Rayleigh-wave and predominant period of S-wave transfer function, a parametric study is conducted using a two-layer model. Three cases of $H/Vs$ ratio are considered, where $H$ and $Vs$ are the thickness and S-wave velocity of the surface layer, respectively. The three cases are actually three predominant



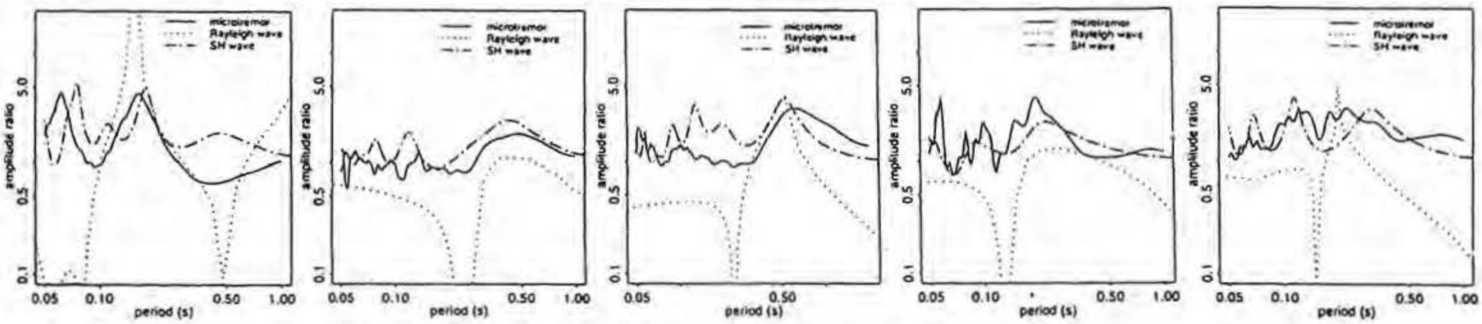
(a) Kodaira. (b) Sodegaura (c) Soka (d) Yotsukaido (e) Fujisawa

Fig. 3 Fourier spectrum at the five sites




(a) Kodaira (b) Sodegaura (c) Soka (d) Yotsukaido (e) Fujisawa

Fig. 4 Fourier spectrum ratio at the five sites.




(a) Kodaira (b) Sodegaura (c) Soka (d) Yotsukaido (e) Fujisawa

Fig. 5 Amplitude ratios ($\dot{u}/\dot{w}$) for microtremor and theoretical Rayleigh-wave plotted with transfer function of S-wave.

period of S-wave ($Ts=4H/Vs$) namely, 0.5 s, 0.75 s and 1.0 s. Also the impedance ratio between the surface and base layers is changed for investigation. Figure 6 shows the relationship between period ratio ($Tr/Ts$) and impedance ratio of the two layers, where $Tr$ is the period corresponding to the peak amplitude ratio of Rayleigh-wave. Figure 7 shows relation between amplitude ratio of Rayleigh-wave and period for different impedance ratios. For the three cases, the predominant period of Rayleigh-wave amplitude ratio approaches the predominant period of S-wave around impedance ratio of 3.5 and around impedance ratio of 5 it is almost equal to the predominant period of the S-wave. For impedance ratio less than 3 there exists no clear peak for the amplitude ratio of Rayleigh-wave. The shape of the amplitude ratio of Rayleigh-wave changes with the change of impedance ratio: with the increase of impedance ratio at first a blunt peak appears and gradually a sharp peak can be seen. The appearance of sharp peak of the Rayleigh-wave amplitude ratio at Kodaira, Soka and Fujisawa may be attributed to comparatively large contrast between the surface and base layer at those sites. On the other hand absence of sharp peak of the Rayleigh-wave amplitude ratio at Sodegaura and Yotsukaido may be attributed to the lack of contrast at those sites. Although the contrast of ground at Fujisawa is comparatively large but the correspondence between the amplitude ratio of Rayleigh-wave and S-wave is not good. The reason may be attributed to the comparatively shallower depth of ground exploration at this site than the other four sites.

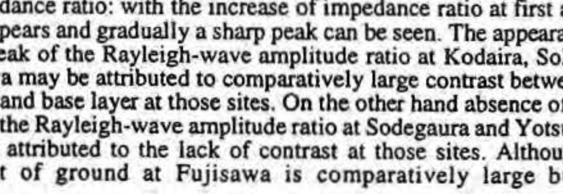



Fig. 6 Relationship between impedance ratio and period ratio (Tr/Ts) of Rayleigh and S-waves.

## DISPERSION CHARACTERISTIC OF VERTICAL MOTION

The frequency-wavenumber ( F-K) spectrum analysis is conducted using microtremors observed at Kodaira, Sodegaura and Soka. At these sites array networks have been extended for the vertical motion. From these array data, the phase velocity and propagation direction have been calculated. Figure 8 shows the apparent velocity of vertical motions of microtremors for six time instants together with the theoretical dispersion curves of the phase and group velocities of the Rayleigh-wave. This figure also shows propagation direction of vertical motions of observed microtremors measured clockwise from the north for the six time instants.

### (a) Kodaira

Although Fourier spectra at Kodaira change for each time instant within

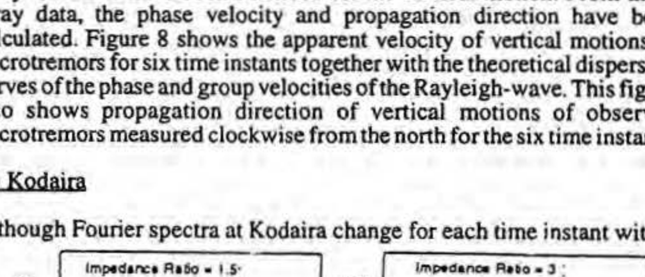



Fig. 7 Amplitude ratio (H/V) of Rayleigh-wave for different impedance ratios (Ts=0.5 s).

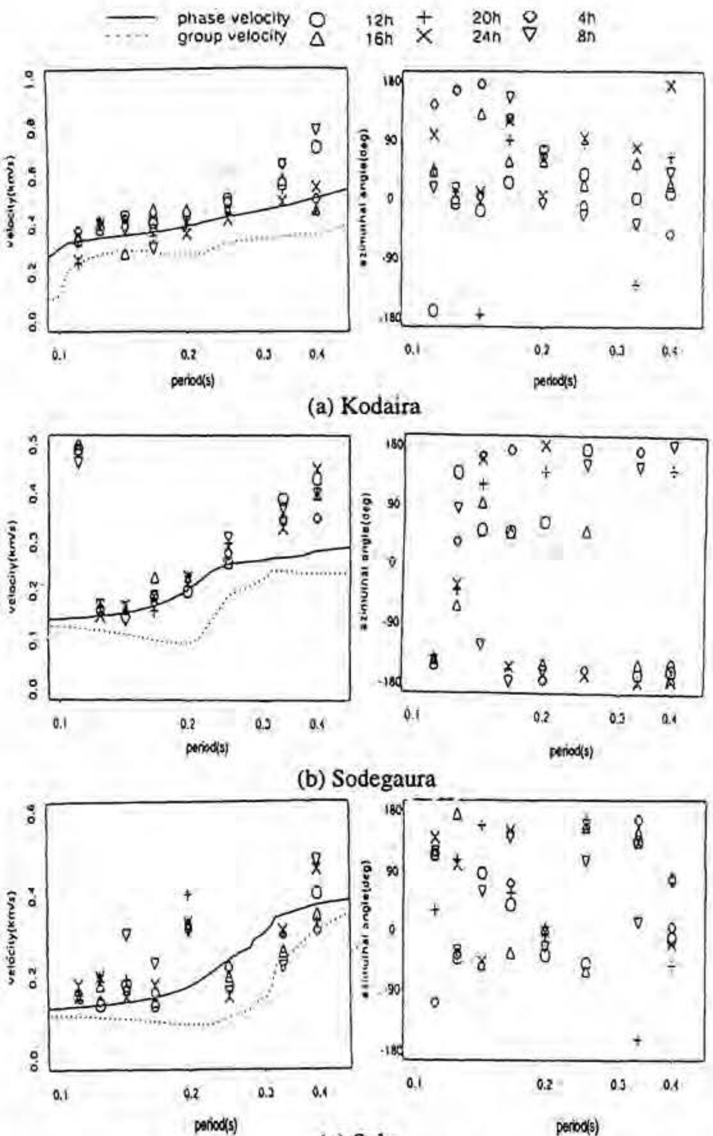



Fig. 8 Apparent velocity of microtremors and dispersion curve of Rayleigh-wave (left) and azimuthal angles of microtremors (right) for six time instants.

a day, the propagation velocity is relatively stable. The vertical motion of microtremor may be more influenced by the soil-structure at the site than the wave source. Again the range of period for which the phase velocity dispersion characteristics of the vertical motion of microtremor is obtained is thought to be dominated by Rayleigh-wave. Roughly the waves are coming from north (0°) to east (90°). The reason may be explained by the fact that New-Ome highway is situated in this direction, which has heavy traffic both in the day and night time. The vertical motion is thought to be generated mainly by this traffic.

(b) Sodegaura

Fourier spectra of vertical motion at Sodegaura for different time instants within a day are comparatively more stable than at Kodaira. Again except the data at period 0.1 s, the dispersion characteristic of Rayleigh-wave is comparatively good. Around this period, the phase velocity becomes extremely high and Fourier spectrum has a large peak. It is understood that a noise is coming from the southwest direction along the whole day. A machine facility is working several tens of meters away from this location round the clock and can be heard clearly from the site. The large value of phase velocity may be attributed to the influence of body wave, which does not decrease much due to short separation distance between the measuring point and the source. For the other period range it is thought that waves are propagating mainly from the southeast direction.

(c) Soka

Like Sodegaura, the Fourier spectrum of the vertical motion at Soka changes little with different time instants within a day. The apparent phase velocities are comparatively stable. If propagation velocity at 0.2 s is removed, the dispersion characteristic of propagation velocity can correspond well with the theoretical dispersion characteristic of the Rayleigh-wave. This wave having a period 0.2 s is propagating roughly from north. A round the clock industrial plant is operating in this direction. The vibration level of this plant is not as clear as Sodegaura but it can be heard and propagation direction can be identified. The propagation direction for other period ranges are scattered. The volume of traffic near this site is small. From the different observed waves propagating from various directions, the wave coming from the nearby plant is thought to be the principal one among the artificial sources.

## CONCLUSION

In the five sites where soil-structures are known, short-period microtremors upto 1 s have been observed using arrays for the investigation of ground vibration characteristics. As a result following conclusions are drawn:

1) Variation of horizontal and vertical Fourier spectra of microtremors is observed with respect to change in time within a day.
2) In most cases, the period corresponding to the peak of the amplitude ratio of microtremors correspond well with the periods corresponding to the theoretical peak of the amplitude ratio of Rayleigh-wave and transfer function of S-wave.
3) From the parametric study of two-layer soil-structure models, good agreement between the period corresponding to the peak amplitude ratio of Rayleigh-wave and the predominant period of the transfer function of S-wave is observed, for impedance ratio greater than 3.5.
4) The propagation velocity obtained from the F-K spectrum analysis of vertical motion of observed microtremor has good agreement with the phase velocity of Rayleigh-wave.

From these, the Rayleigh-wave is thought to be predominant in the short-period microtremors. However, it seems difficult to judge whether microtremors are composed of the Rayleigh-wave or the body wave from the one-point observations.

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