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ESTIMATION OF THE SITE RESPONSE IN THE KUSHIRO CITY, HOKKAIDO, JAPAN, USING MICROTREMORS WITH SEISMOMETER ARRAYS

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ABSTRACT

Determination of geological structures more than several hundred meters deep is important for estimation of site response in urban areas where conventional seismic exploration methods are difficult to apply. We observed microtremors with 7 or 10 vertical - component seismometers arranged in triangular arrays in the Kushiro city, Hokkaido, Japan. The Spatial autocorrelation method was applied to microtremor data and phase velocities of the frequency range from 0.8 Hz to 3.6 Hz were obtained. We estimated S - wave velocity structures from the observed phase velocities by assuming that the main part of the observed microtremors consisted of the fundamental mode of Rayleigh waves. The estimated S - wave velocity structures are consistent with lithological layer boundaries. Theoretical site response was calculated based on the S - wave velocity structures for SH - wave vertically incident. The theoretical site response is in good agreement with Fourier spectra of horizontal - component obtained from seismograms. The use of microtremors is effective means for determination of the geological structures and site response can be evaluated in urban areas.

KEYWORDS

Microtremors; seismic array; spatial autocorrelation method; Rayleigh wave; S - wave velocity structure.

INTRODUCTION

The Kushiro - oki Earthquake (M7.8) of January 15, 1993, provided us quite an important suggestion of about site effect. The Japan Meteorological Agency (JMA) observed the acceleration of 0.92g at the Kushiro Observatory (Fig.1). The Port and Harbor Technical Research Institute (PHRI), which is about 3 km west of JMA, observed the acceleration of 0.47g (Fig.1). The difference of the ground motion is due to the change of surface geology in the Kushiro city. So we observed phase velocities in microtremors with seismometer arrays at five sites and tried to estimate geological structures down to a depth of several hundreds meters deep in the Kushiro city (Fig.1).

The microtremors are feeble ground motions caused by movements of traffic or machinery, local wind effects, rain storm, and sea waves. The microtremors can be observed at any time and in any place with a fairly stable spectrum. Seismologically, the microtremors consist of mainly surface waves rather than body waves or

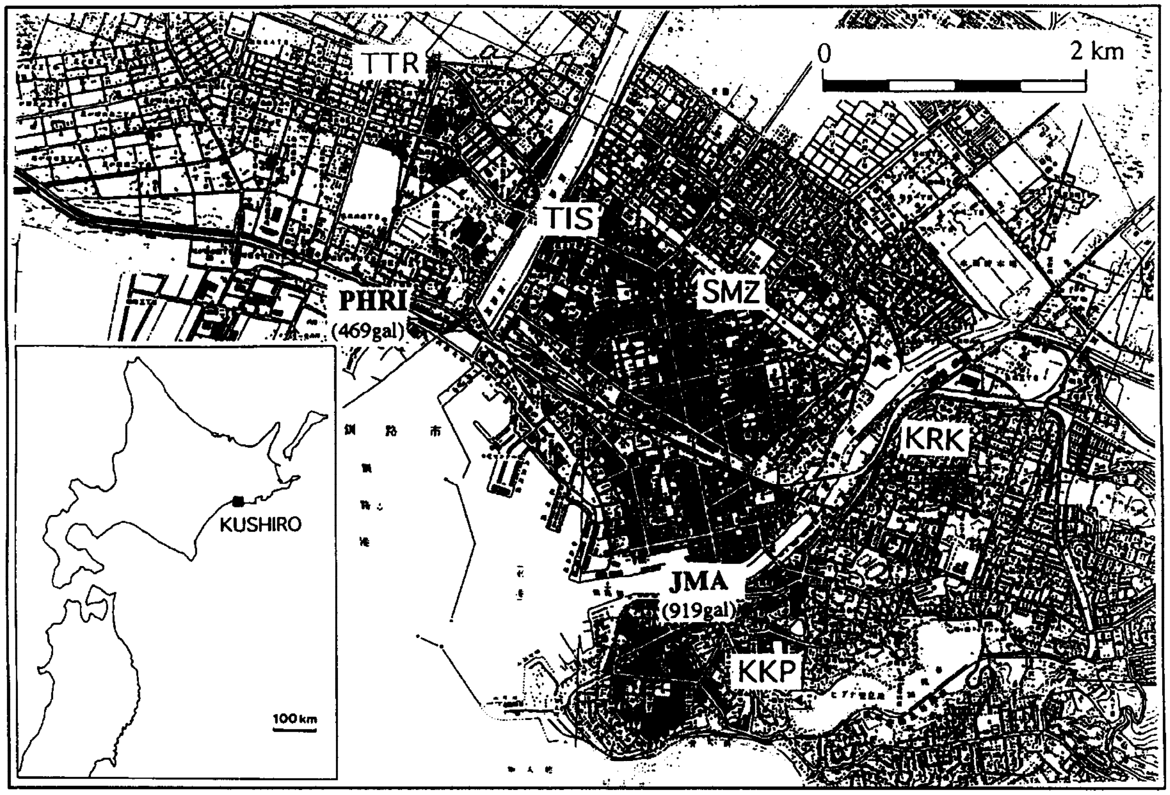

Fig. 1. Map showing observation sites of microtremors in the Kushiro city.

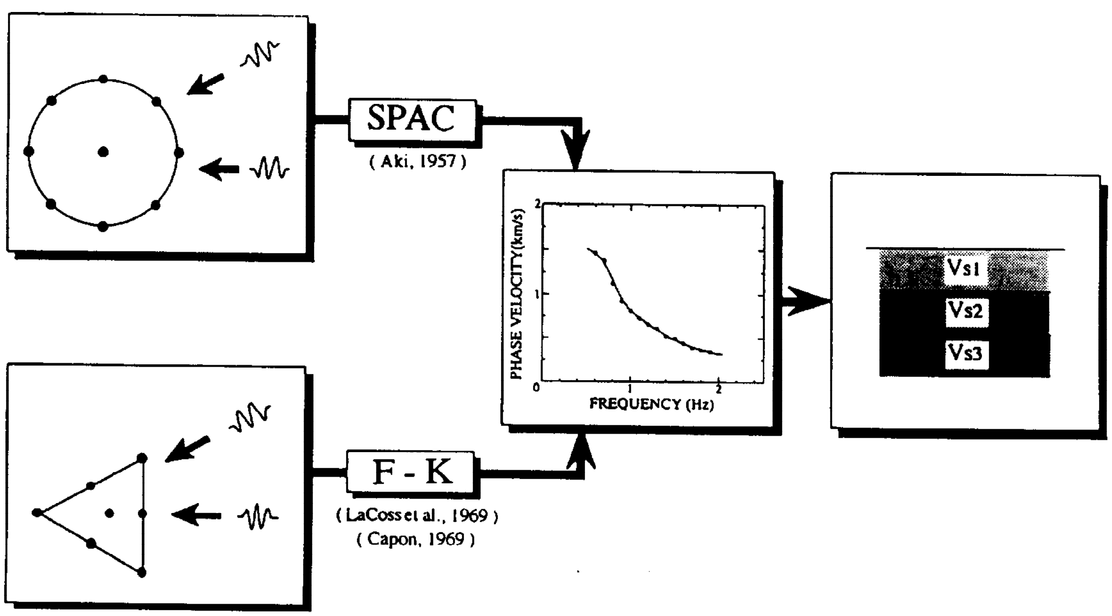

Fig. 2. Flow chart of procedure of an exploration technique using microtremors.

scattered waves. The phase velocities of surface waves can be extracted from microtremors in the form of dispersion using Spatial autocorrelation method (SPAC method; Aki, 1957) or Frequency - Wavenumber method (F - K method; LaCoss *et al.*, 1969, Capon, 1969). The inversion process applied to the phase velocities can provide geological structures more than several hundreds meters deep. Fig.2 shows a flow chart of the procedure required in the exploration technique using microtremors.

OBSERVATION

Each seismic array was composed of 7 or 10 stations, and the vertical - component seismometer (PESL73V) were used. We used two or three arrays with different radius at same site. The seismometers were adjusted to the natural period of 8.0 s. Each seismometer was connected to a hand - made digital data recorder with precise clock (Furumura and Moriya, 1988) using large aperture array or a DR-F1 digital data recorder by cables using small aperture array. The sampling frequency of recorder was 200 Hz and duration of observation was about 20 or 30 minutes at each array. Fig.3 shows an example of microtremors recorded at TTR94C ($R_C = 0.040$ km).

ANALYSIS

There are two principal methods to the measurement of phase velocities from microtremors: SPAC method and F - K method.Since SPAC method was superior to F - K method for estimation of phase velocities from microtremors, SPAC method was employed in this paper. According to a paper by Aki (1957), the spatial autocorrelation coefficient ρ of a give frequency f takes the form,

$$\rho(f, r) = J_0\left(\frac{2\pi f}{c(f)} r\right)$$

where J_0 is the zero order Bessel function, $c(f)$ is the phase velocity of surface wave, and r is the radius of circular array. Fig.4 shows spatial autocorrelation coefficients of the frequency range from 1.5 Hz to 3.0 Hz at TTR94C. The solid line in the figure is the zero order Bessel function fitted to the spatial autocorrelation coefficients. Phase velocities estimated by SPAC method at two sites are shown in Fig.5, which clearly show dispersion properties in the frequency range from 0.8 Hz to 3.6 Hz. Theoretical phase velocities of the fundamental mode of Rayleigh waves are shown in Fig.5 by solid line, calculated for the optimum structural models. Fig.6 shows the S - wave velocity structure estimated at TTR and TIS, in which the basement has an S - wave velocity of about 0.76 km/s. The depth of the basement becomes shallower from the west to the east in the Kushiro city. Fig.7 shows the lithological layer boundaries obtained from drill holes. The S - wave velocity structures are consistent with the lithological layer boundaries.

SITE RESPONSE

In the Kushiro city, the strong seismometers have been installed at 24 sites by the ESG (the Effects of Surface Geology on Seismic Motion) committee since the Kushiro - oki Earthquake occurred. Since a number of strong motions have been observed, we compared the Fourier Spectra obtained from seismograms with the theoretical site response. Fig.8 shows the theoretical site response for SH - wave vertically incident at two sites by employing the optimum S - wave velocity models without taking the attenuation factor into account. The frequency of the first maximum peak is about 0.8 Hz and 1.0 Hz at TTR and TIS, respectively. Fig.9 shows the observed Fourier spectra of horizontal - component at two sites. The frequency of the characteristic Fourier spectra at TTR and TIS are 0.7 Hz and 1.0 Hz, respectively. The theoretical site response is in good agreement with the characteristic site response observed.

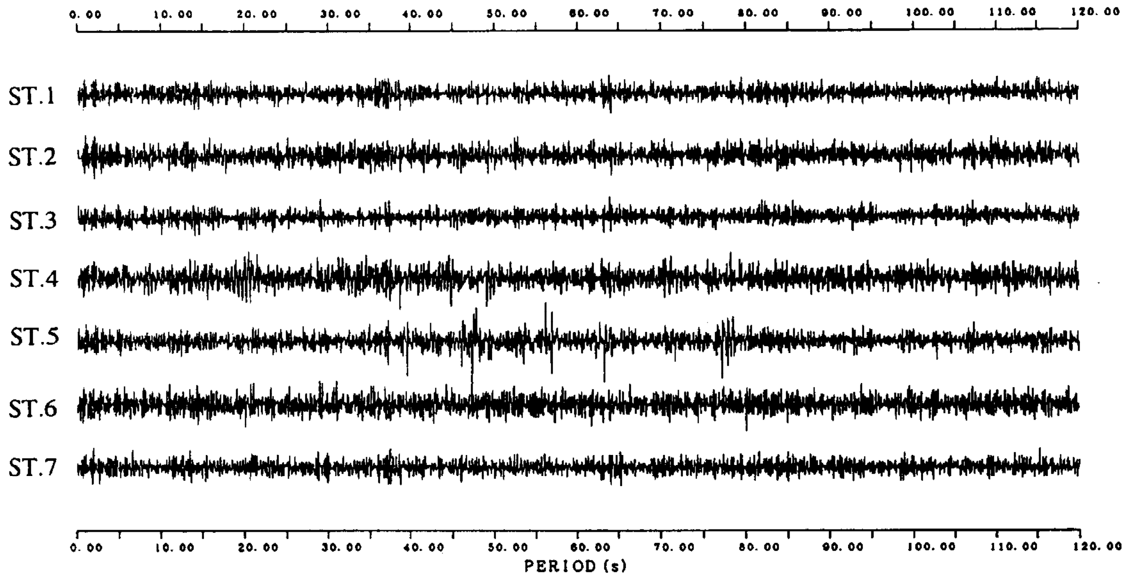

Fig. 3. Microtremors recorded at TTR94C ($R_C = 0.040$ km).

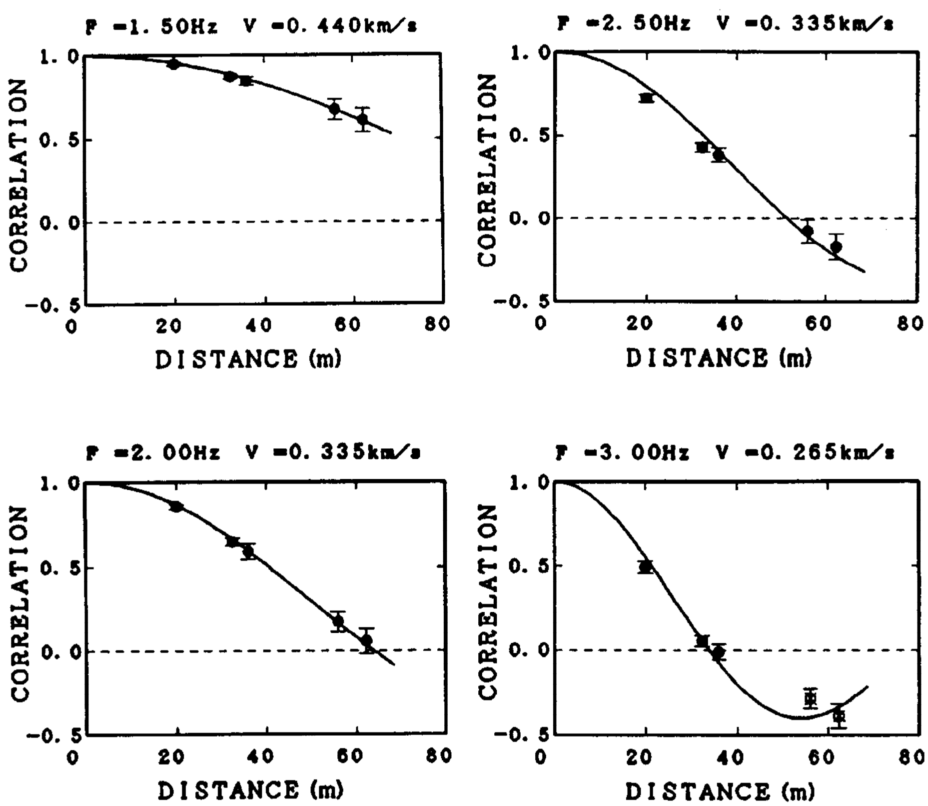

Fig. 4. Spatial autocorrelation coefficients of the frequency range from 1.5 Hz to 3.0 Hz at TTR94C. Solid lines denote the zero order Bessel function fitted Spatial autocorrelation coefficients.

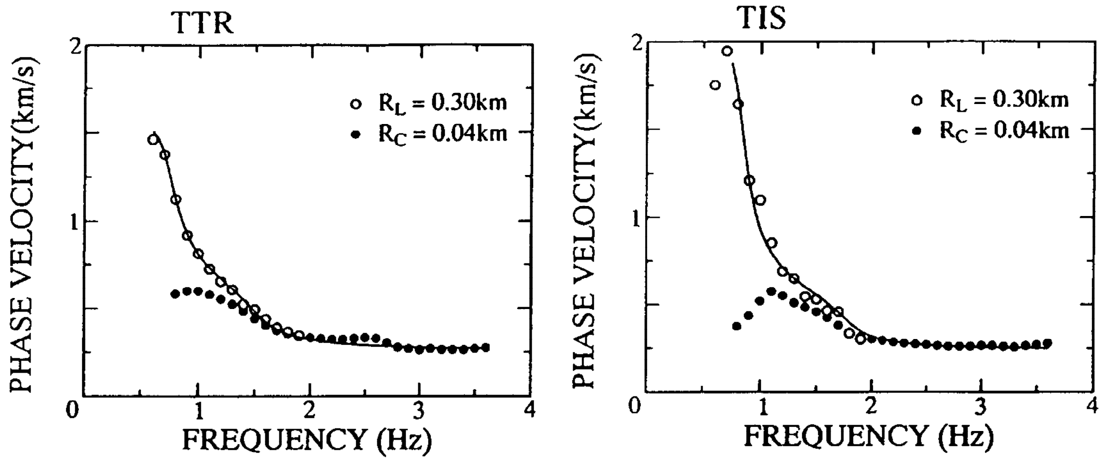

Fig. 5. Observed phase velocities in microtremors at TTR and TIS.
Open circle : R_L = 0.30 km Solid circle : R_C = 0.04 km
Theoretical phase velocities of the fundamental mode of Rayleigh waves calculated for the final models are also shown by solid line.

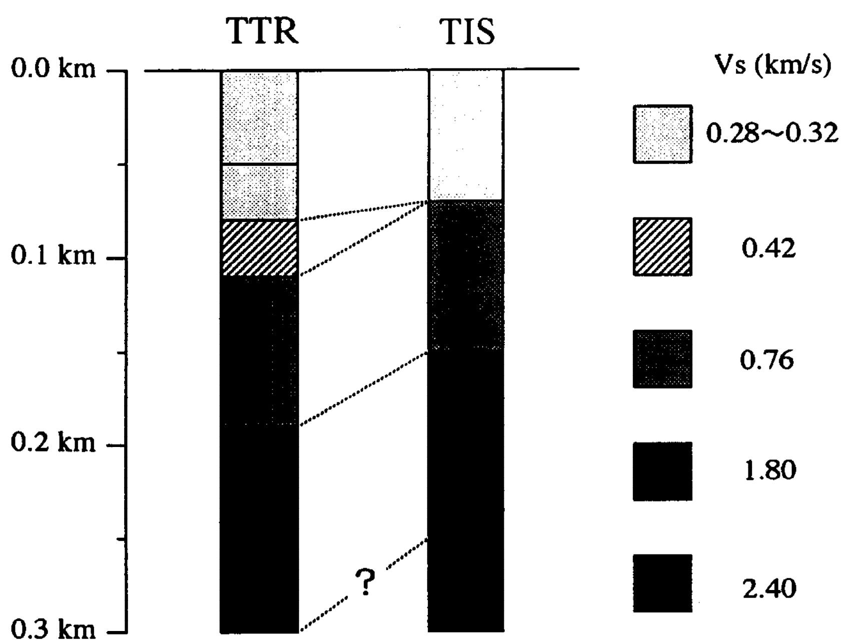

Fig. 6. S - wave velocity structures at TTR and TIS.

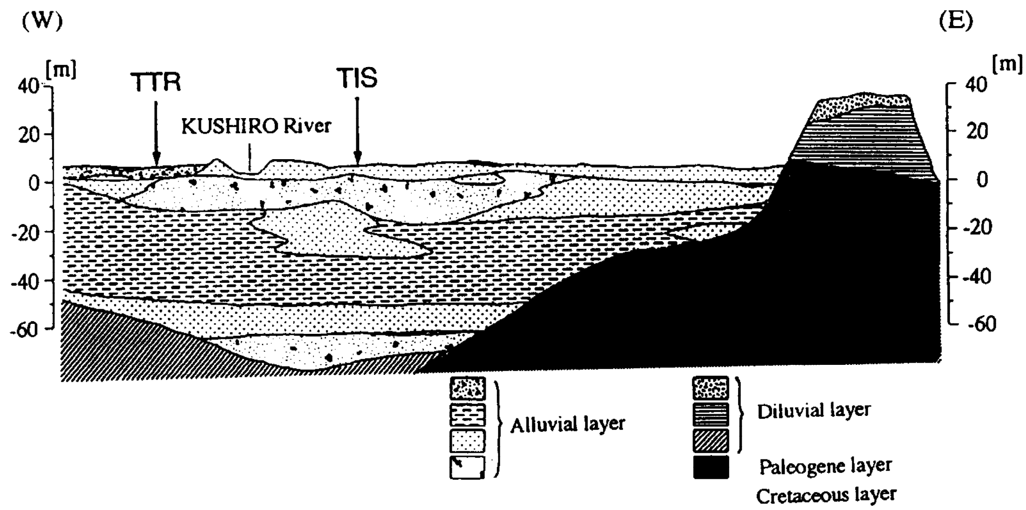

Fig. 7. Lithological layer boundaries in the Kushiro city.

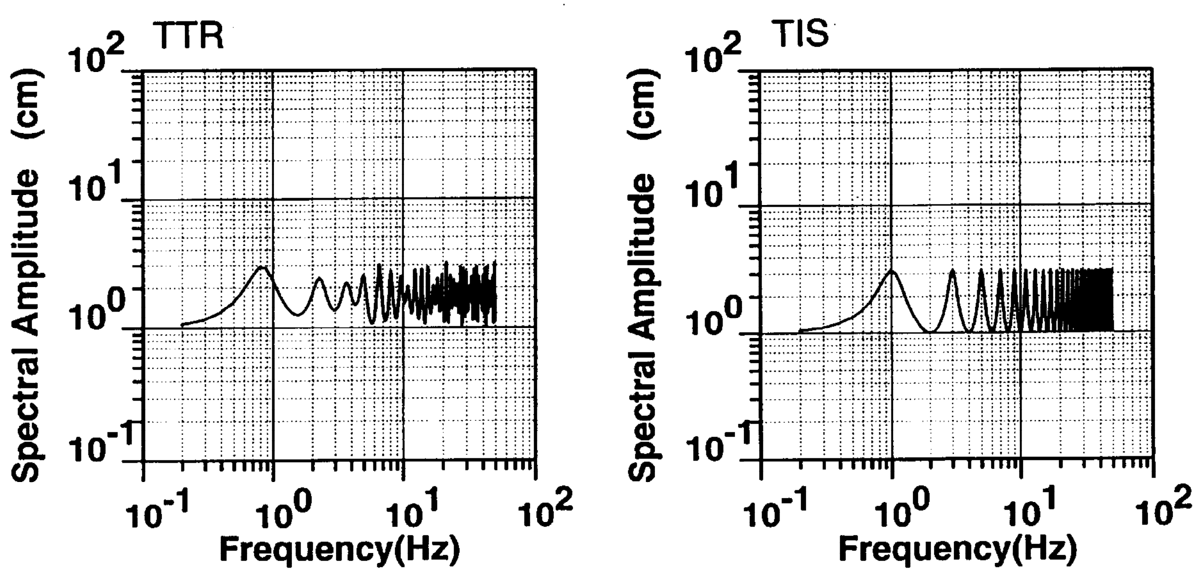

Fig. 8. Theoretical site response calculated from the estimated S - wave velocity structures at TTR and TIS for SH - wave vertically incident.

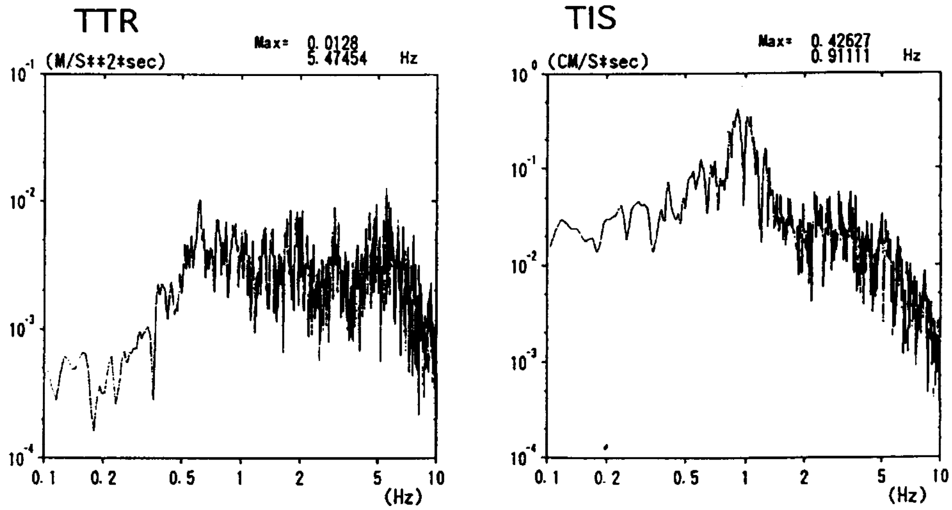

Fig. 9. Fourier spectra of horizontal - component obtained from seismograms at TTR and TIS.

CONCLUSION

Phase velocities of the Rayleigh waves in microtremors were successfully measured in the frequency range from 0.8 Hz to 3.6 Hz by using SPAC method. We could estimate the S - wave velocity structures down to a depth of about 300 m based on the observed phase velocities. The depth of the basement, which had an S - wave velocity of about 0.76 km/s, was found shallow from 100 m to 70 m varying towards east in the Kushiro city. The geological condition also supports our result that the depth of the basement layer is shallower on the east than on the west side of the Kushiro city. The theoretical site response was calculated based on the S - wave velocity structures for the SH - waves vertically incident. The frequency of the first maximum peak changed from 0.8 Hz to 1.0 Hz towards east in the Kushiro city. The change of the peak frequency is in good agreement with the Fourier spectra of horizontal - component obtained from seismograms.

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