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APPLICATION OF INTERSTATION SPECTRAL RATIO TECHNIQUE OF LONG-PERIOD MICROTREMORS TO ESTIMATE SITE EFFECTS

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ABSTRACT

The applicability of interstation spectral ratio technique for long-period microtremors was examined for assessing ground vibrational characteristics in a period range more than 2 sec. We conducted continuous and temporary microtremor measurements in the northwestern Kanto plain, Japan. First, stability of long-period microtremors spectra was investigated using data from the continuous measurements. The results evidently indicated that the interstation spectral ratio technique can effectively remove source effects in the long-period microtremors. Then, spatial distribution of spectral ratio at each site to that at the reference site on a basement was obtained. They are in a good agreement with a basement depth contour derived from a gravity survey.

KEYWORDS
microtremors; long-period motion; site effects; sedimentary basin; Kanto plain

INTRODUCTION

The applicability of microtremors in earthquake engineering has been examined since the pioneer work by Kanai and Tanaka (1961) because the techniques can be one of the most convenient methods to assess ground vibrational characteristics. In particular, application of long-period microtremors at periods more than 2 sec has been investigated in the last two decades for an evaluation of long-period strong motion in a deep basin with increasing number of large man-made structure.

Probably, the easiest procedure is to find a predominant period that characterizes a transfer function of subsurface structure. However, it is sometimes difficult to identify such a predominant peak. Then, spectral ratio of vertical and horizontal microtremors at a single site can be used to know such a site-characterizing peak (Lermo *et al.*, 1993). Furthermore, an interstation spectral ratio that is defined as ratio of spectrum at each site to that at a reference site is applied (e.g., Kagami *et al*, 1982). More sophisticated approach is based on array measurements of microtremors for revealing a subsurface velocity profile (e.g., Horike, 1985), though it requires much effort in data acquisition.

In this study, we examined an applicability of the interstation spectral ratio of long-period microtremors from measurements in the northwestern Kanto plain, Japan. The area is of special interest, because a deep structure of the sediments exhibits a clear three-dimensionally irregular geometry in a margin of the basin (Hagiwara *et al.*, 1987).

INVESTIGATED AREA

The investigated area is of 20km*20km in the Higashi-Matsuyama district in the northwestern part of the Kanto plain as shown in Fig. 1. The western side of the area belongs to mountain, while the other sites are more or less covered by the sediments. The subsurface structure in the area exhibits three-dimensionally complex features. The basement depth deduced from a gravity surveys (Hagiwara *et al.*, 1987) is shown by the contour lines in Fig. 1. The basement depth is less than 0.5 km in the western mountains. Toward the southeast, the basement increases its depth and reaches at a depth of more than 2.5 km in the southern end of the area. In the north of the area, there exists an up-lifted zone around F2 where the basement depth becomes less than 0.5 km. A seismic survey near the station D4 suggested that the basement is located at a depth of about 1.3 km (Muto *et al.*, 1982). A trial survey of an S-wave velocity profile beneath the station D4 was conducted by using a spectral ratio of vertical and horizontal microtremors (Yamanaka *et al.*, 1994).

MEASUREMENTS

We conducted microtremor measurements at 55 sites in the area as shown in Fig. 1. These sites were arranged in grids with a station spacing of about 2 km. At each site, we set velocity-type seismometers in the three components whose frequency characteristics are flat up to 10 sec. Signals from the seismometers were filtered by a low-pass filter with a cut-off frequency of 10 Hz. Then, the signals were amplified by a DC amplifier, and recorded by a digital recorder with a sampling interval of 0.02 sec.

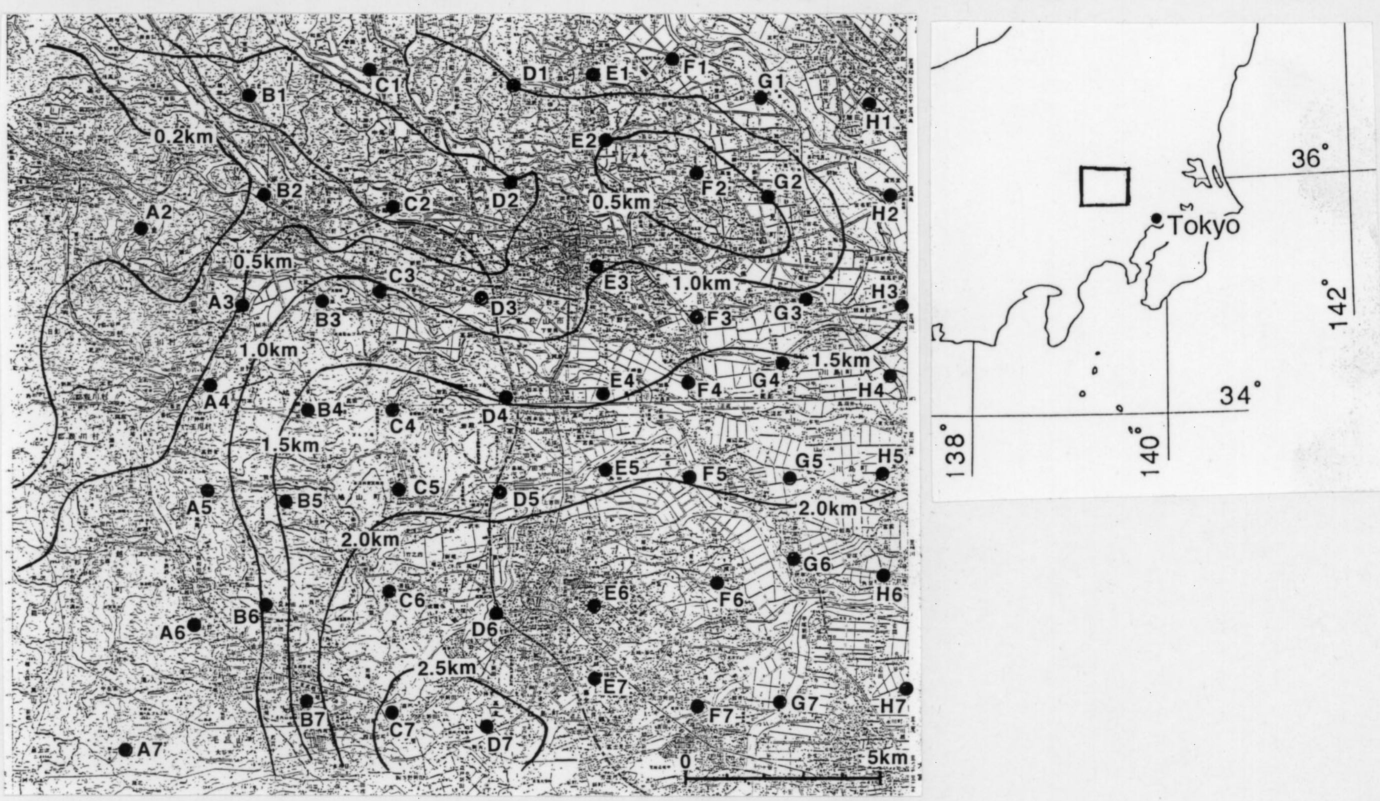


Fig. 1 Locations of observation sites.

The measurements were done during four days in January, 1994 in two types of measurements. One is the continuous measurements in which we recorded microtremors every two hours in the entire observational term at the station of D4 that is located in the center of the area. We also performed short-term continuous measurements at the four stations of A2, F2, C3 and D7. A2 is located on a firm rock and can be regarded as a reference site in our investigation of the interstation spectral ratio. The short-term continuous measurements are composed of 6 records of microtremors that were obtained every two hours starting from an evening to the next morning in the observation term. At the other sites, a temporary measurement was done by recording 10 min. data of microtremors in a day time.

RESULTS OF CONTINUOUS MEASUREMENTS

In this section, stability of microtremors is investigated by using the records obtained in the continuous measurements. We calculated Fourier spectra from the records with a duration of 327.68 sec by an FFT. The calculated spectra were smoothed by the Parzen spectral window with a frequency band of 0.05 Hz. Two horizontal spectra were averaged to generate a horizontal spectrum that will be discussed later. Although a spectral ratio of vertical and horizontal microtremors at a single site is interesting to investigate with a relation to subsurface structure (Yamanaka *et al.*, 1994), we concentrate ourselves to examine the interstation spectral ratio in this study.

Fig. 2 shows the horizontal spectra at the station D4 where the measurements were continuously done every two hours. Horizontal spectra simultaneously obtained at A2 on a firm rock are also shown in the figure. The spectra at the two sites have similar shapes in the first three days. However, they vary significantly in a period range from 2 to 10 sec from 1/17 to 1/18. This clearly indicates that a predominant period of a microtremor spectrum can be time-variant.

This time-variant feature of the microtremors at the two sites on the sediment and the basement is investigated in detail by calculating spectral amplitudes averaged in various period ranges. As shown in Fig. 3, the variations for the spectral amplitudes in period ranges longer than 2 sec at D4 on the sediments are very similar to those at the basement site. Therefore, this variation is probably attributed to effects of microtremor sources. Furthermore, a some procedure should be made to remove the source effects. On the other hand, the amplitudes at periods less than 1 sec vary differently with time at the two sites. This indicates that the short-period components of the microtremors are originated from different types of sources.

STABILITY OF INTERSTATION SPECTRAL RATIO

Ratios of the spectra at D4 to those at A2 are calculated. As expected from the spectral variations with time, the interstation spectral ratios shown in Fig. 4 are stable at periods longer than around 2 sec. The ratios are unstable in a period range longer than about 8 sec, because of unstable amplitudes of the spectra at A2 that are used as a denominator. The variation of the spectral ratio with time was examined by calculating an average of the ratios in the same period ranges as shown in Fig. 5. The ratios at periods more than 2 sec are stable. However, the ratios in the shorter periods have large standard deviations, indicating the difficulty of the usage of short-period interstation spectral ratio technique to assess earthquake ground motion in a wide area, like an entire of a city.

Next, we calculated the interstation spectral ratio for various station pairs by using the records from the

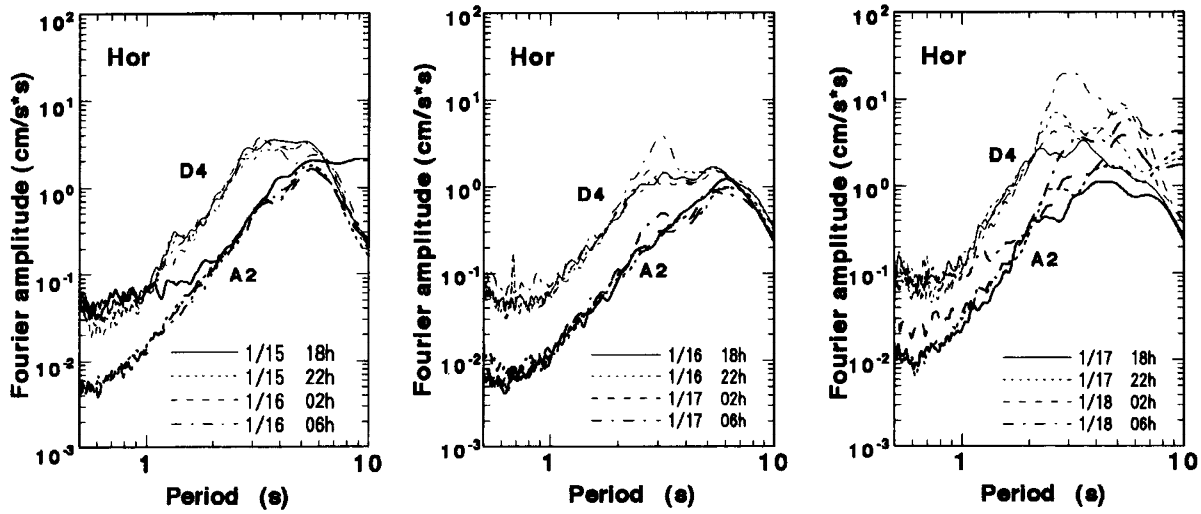


Fig. 2 Horizontal spectra of microtremors observed at D4 on sediments and A2 on basement.

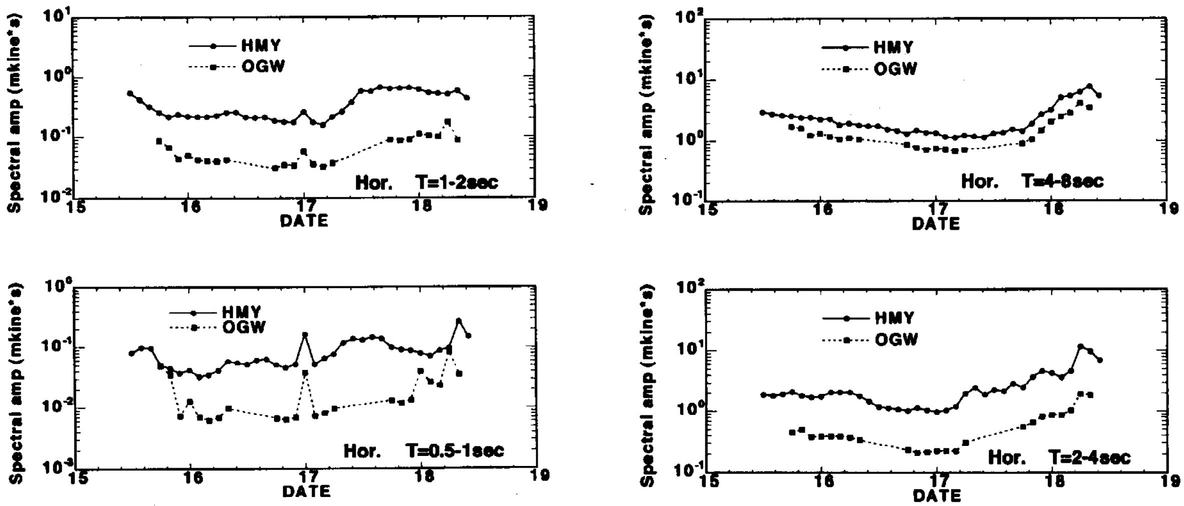


Fig. 3 Variation of spectral amplitudes at various period ranges. Solid and broken lines indicate variations at D4 and A2.

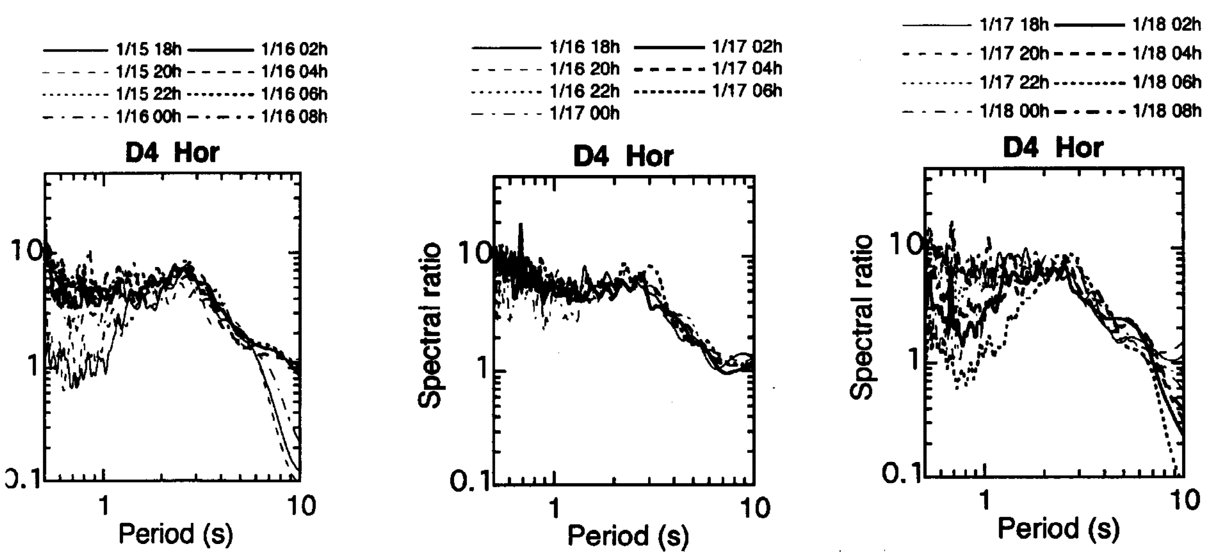


Fig4. Ratio of spectra at D4 to that at A2

short continuous measurements. Fig. 6 displays the horizontal spectra at the stations C3, D7, and F2, and their ratios to those at the reference site of A2 that were recorded simultaneously. All the spectra ratios are very stable with time at periods longer than 1 sec. In particular, the spectral ratios at D7 have small variations, in spite of the large variations of the spectral amplitudes in which the peak periods changed from 2 to 6 sec within 10 hours. It is very interesting that the spectral ratio for the station F2 is almost one at all the period ranges.

RESULTS OF TEMPORARY MEASUREMENTS

All the records obtained from the temporary measurements were processed in the similar manner to generate spectra. The results in the previous section suggested a simultaneous recording is needed to remove source effects of microtremors. In this study, the microtremors were continuously observed at the station D4. Therefore, we used these spectra to cancel the source effects. Here, we assumed that the spectral ratios of D4 to those at A2 during the temporary measurements are stable and equal to the average spectral ratio between the two sites. The average spectral ratio, H(w), was calculated from all the spectral ratios. We had no records at A2 in the day time, when the temporary measurements were done. Therefore, synthetic spectra at A2 were generated by using H(w) and a spectrum at D4, which was recorded at a time when the measurement was done at each temporary site. This synthetic reference spectrum was used to remove source effects from the spectra at the temporary sites.

Some of the horizontal spectral ratios at the temporary sites are shown in Fig. 7. Most of the stations along the line A are located in the mountain area, and the spectral ratio are almost flat over a wide period range, except for the station A5. The ratios along the line B can be roughly divided into two groups that are characterized by the large and small ratios at periods of 2 to 6 sec. The ratios at the northern sites along the line D have smaller values than those at the southern sites, suggesting the existence of thicker sediments. The ratios in a period range shorter than 1 sec become large at the sites in the line H, because most of the sites along the line are located in a populated area. The spectral ratio at F2 is of factor of one in all period range and the ratios for the neighbor stations of F1 and F3 are much larger. This is due to the up-lifted basement near F2 that can be seen in the basement depth map in Fig. 1.

SPATIAL DISTRIBUTION OF SPECTRAL RATIO

As discussed previously, spectral ratios at periods shorter than 1 sec are unstable in this large area. Therefore, we pay our attentions to distribution of the spectral ratios in a period range from 2 to 8 sec. Fig. 8 shows the ratio of spectrum at each site to those at the reference site of A2. The ratio was calculated by averaging the amplitudes at periods from 2 to 8 sec. Generally, the ratios are small in the west and north of the area, and they become larger toward the southwest. These features are in a good agreement with the basement depth map shown in Fig. 1. In particular, contour line with a ratio of 2 is well coincidence with basement/sediments boundary that is characterized by a contour for a basement depth of 0.5 km. Since the long-period microtremors are mainly composed of surface waves (e.g., Horike, 1985; Yamanaka *et al.* 1994), the ratio distribution can be interpreted as amplification of surface waves due to the deep sedimentary layers. Although the sediment-sites show large amplifications, the location of the maximum amplification is different from the position having the deepest basement depth. This is probably due to three-dimensional effects of the basin geometry.

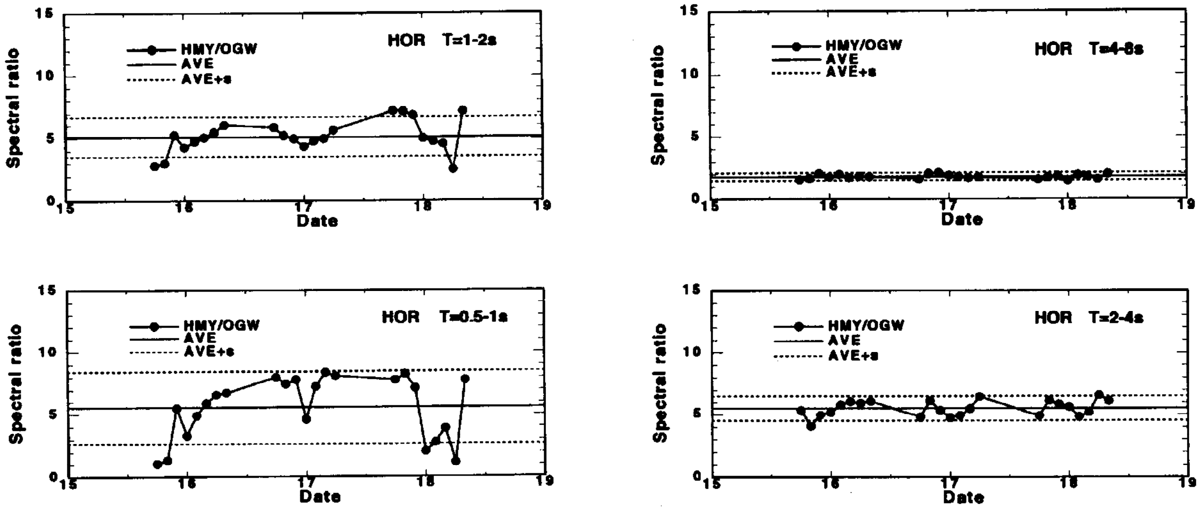


Fig.5 Variation of spectral amplitudes at various period ranges.

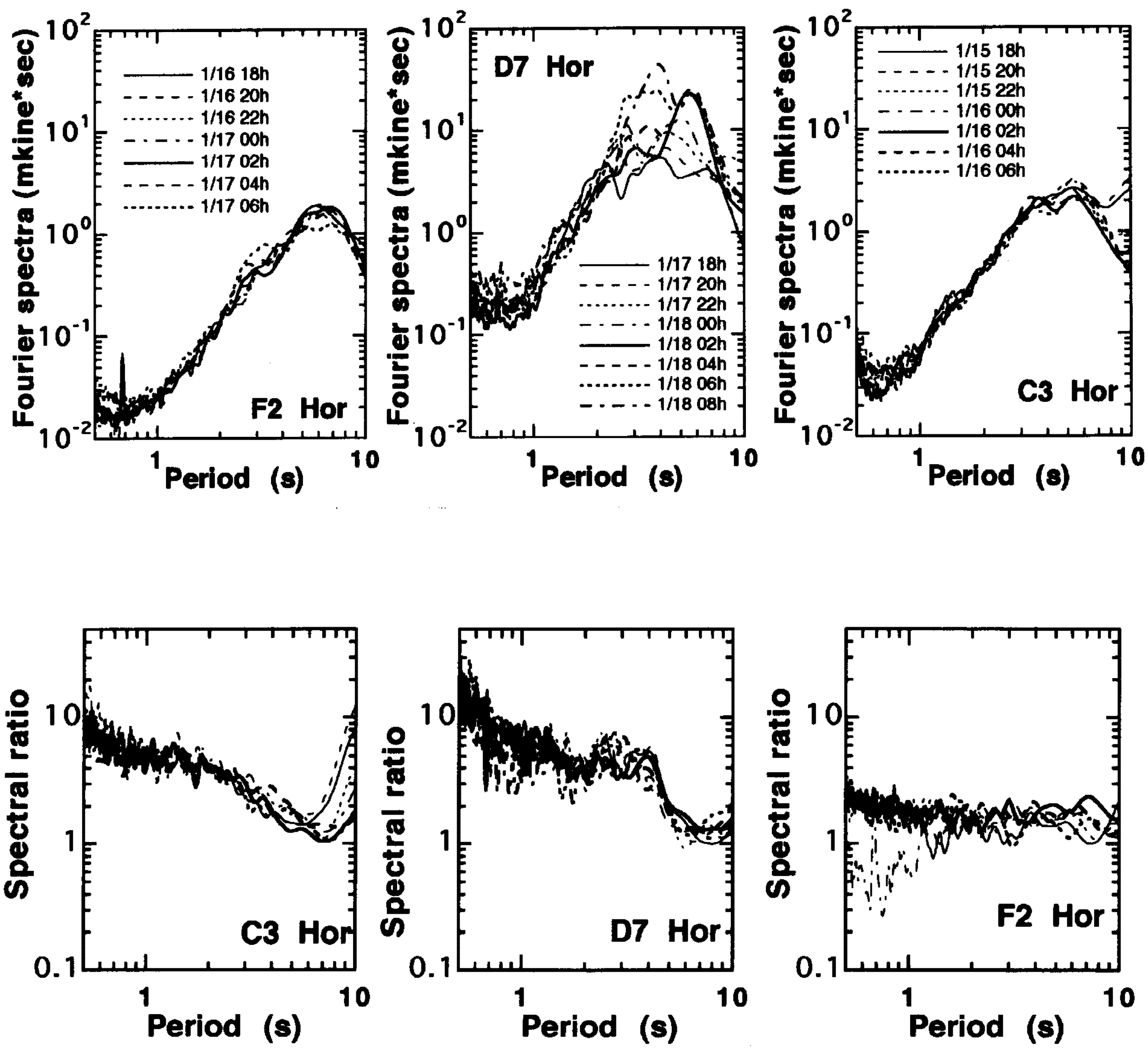
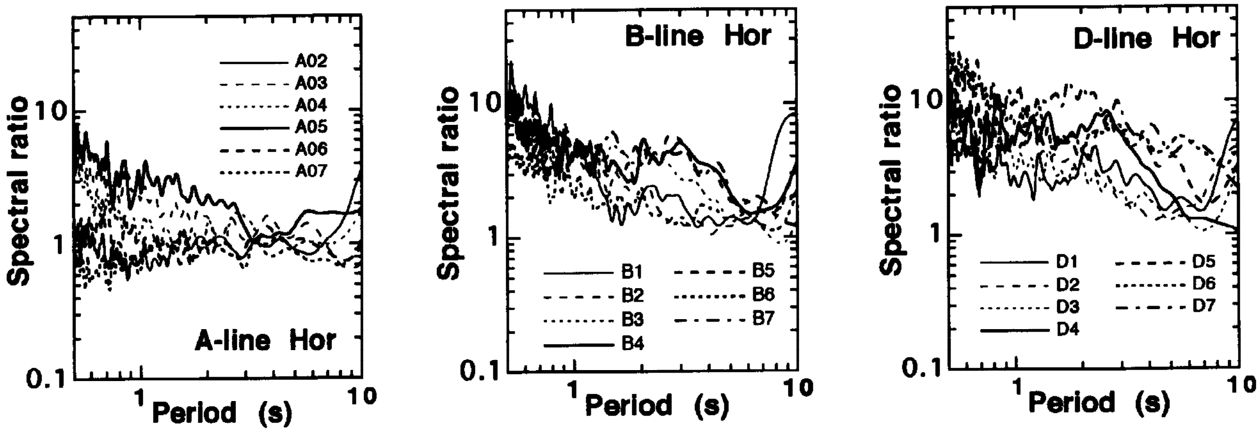


Fig. 6 Spectra and spectral ratios at C3, D7, F2



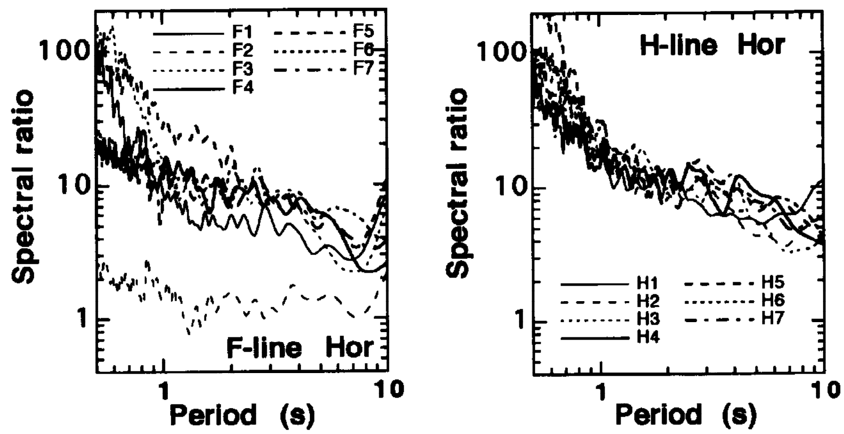


Fig. 7 Ratio of spectra at the temporary sites to that at A2.

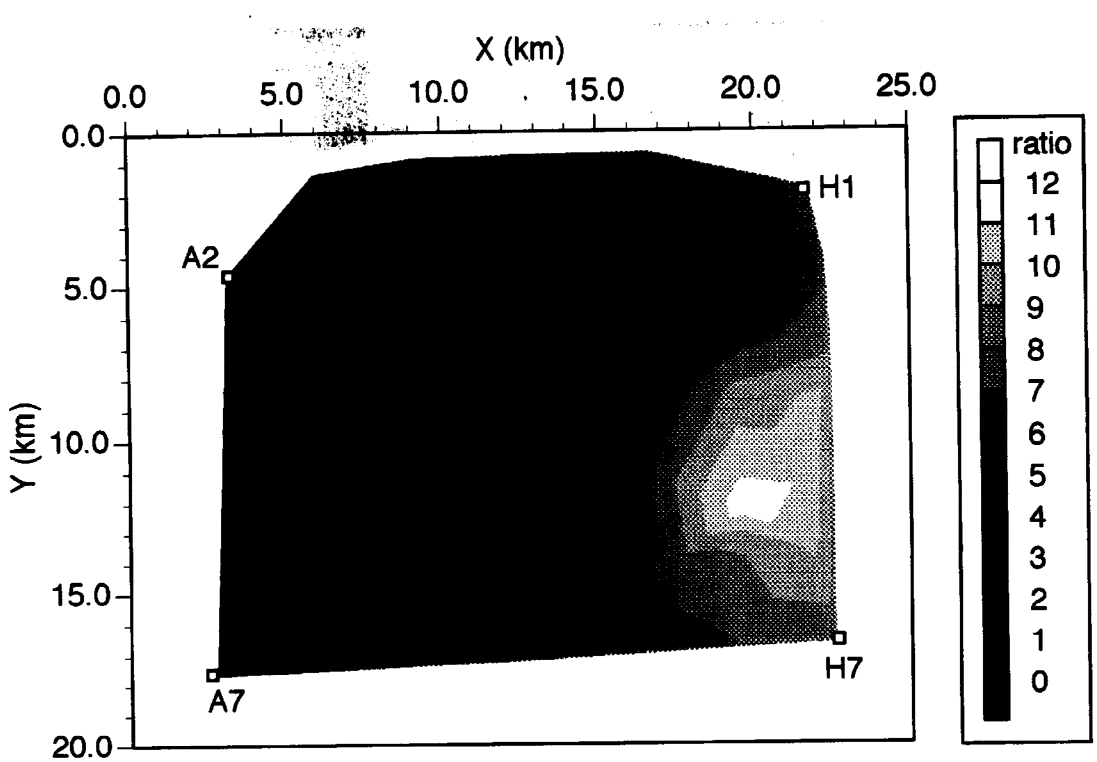


Fig.8 Distribution of spectral ratio of horizontal microtremors at periods from 2 to 8 sec.

CONCLUSIONS

Measurements of long-period microtremors were conducted in the northwestern part of the Kanto plain, Japan, to examine the applicability of the interstation spectral ratio technique, in which the ratio of spectrum at each site to that at a reference site on a firm rock was used. We confirmed from the continuous measurements that the spectral ratio was stable with time in a period range longer than 2 sec. It was suggested the need of simultaneous measurements in the interstation spectral ratio technique to remove source effects. The distribution of the long period spectral ratio agrees well with a basement depth map, suggesting the applicability of the procedure to assess long-period earthquake ground motion. Since it had been shown in previous researches that surface waves have large contributions to long-period microtremors, the distribution of the spectral ratios probably indicates an amplification of surface waves in the three-dimensional basin. A three dimensional modeling of surface wave propagation is addressed as a future work for physical understanding of the observational results.

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