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Observation of Microtremors in the Tsukuba Area, Japan, using a Portable Broadband Seismometer

By

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with 1 Table and 7 Figures

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Abstract: Studies of microtremors have been advanced by different approaches, that is, a variety of observational studies and analyses, for both the short-period and the long-period ranges since the microtremors for each range have their own source and site characteristics in time and space. We, therefore, conducted microtremor observation around Tsukuba City, Ibaraki, Japan, in July and August, 1991, in order to clarify site characteristics of six locations around the Tsukuba Mountain, deploying a portable broadband seismometer (Streckeisen STS-2) in the field of subsurface structure and studying ground motion in both frequency ranges, simultaneously. By a comparison with an STS-1 seismometer, the STS-2 gives reliable frequency ranges higher than 0.09 Hz and 0.05 Hz in horizontal and vertical components, respectively. The correlation of the reference site and the other sites implies that the source of microtremors shares common characteristics for the lower range (< 1 Hz) and changes temporally by human activities for the higher range (> 1 Hz), particularly 1.2 ~ 2.5 Hz, in this area. Three types of dominant peak frequencies for the range of 0.1 ~ 1 Hz are revealed: (1) the peak frequencies ranging from 0.2 to 0.3 Hz observed near Mt.Tsukuba can be explained by the topographic high model of Bard (1982). Two frequency peaks ranging (2) from 0.2 to 0.4 Hz and (3) from 0.5 to 0.8 Hz, observed at the stations on alluvials, are related to any vertical resonance in soft layers, consistent with other geological information. Amplitude ratios at sedimentary sites with respect to TSK (Mt.Tsukuba), a rock site, are greater than unity over 5 Hz where the ratios are reported to be smaller than unity in many areas, which implies relatively hard sedimentary layers in the Tsukuba area.

CONTENTS

I. Introduction

It is well known that ground motion by an earthquake depends on not only the source and path effects but also the site characteristics. The short (< 1 sec) and long-period (one to several seconds) microtremors corresponding to the shallow (< some 10 m depth) and deeper (100 m ~ some 1 km depth) underground structures are studied in the field of earthquake engineering (Kagami, 1989). Most seismometers used for the observation of short-period microtremors have covered only narrow high frequency range (> 1 Hz), because the natural period of many buildings is shorter than one second and their structures are mainly affected by ground motion for this rang. The site characteristics from geological and seismological data have been studied for the short-period microtremors by estimating the dominant frequency and comparing the amplification factors with spectral or power spectral ratio of microtremors among sites on the ground surface (e.g., Kanai et al.,1961; Ohta et al.,1978; Akamatsu et al.,1992). Since the period of a large earthquake is longer than the natural period of these seismometers (~ 1 sec) and some of modern buildings become larger and more variable in size and shape, the observation in broader and lower frequency rang is required to estimate site effects of ground motion to those buildings. Since the long-period microtremors are quite variable in time and space in contrast to the short-period which can be assumed that the incident spectra are stationary white, array observation may be needed at a few times to make good estimate of subsurface structure (Kagami,1989). From this point of view, the site characteristics of long-period ground motion have been studied using a dense array of seismograms (e.g., for the frequency range from 0.5 to 3.0 Hz by Horike (1985); 0.1 to 10 Hz by Kinoshita (1988); 0.2 to 1 Hz by Maiguma et al., (1990)). Other resent trends of microtremor studies are estimating the shear wave velocity structure from the dispersion curve of surface waves identified by array observation with many seismometers (e.g., Horike,1985; Matsushima et al.,1985,1989; Irikura,1989, Kawase,1993), and determining seismic wave velocity structure directly on the basis of array and borehole observations (e.g., Kinoshita,1988), as the degree of sophistication in measurement increases in the above order.

In general, the long-period seismometers are not so portable because of its heavyweight and they require technical operations and much time for installation. Seismometers used for the long-period microtremor observations are required to be lightweight and small size with a long natural period in order to be convenient for field works and traveling observations. Some seismometers have been improved for usefulness (e.g., Suzuki et al., 1970). We, therefore, attempted to use a portable Streckeisen STS-2 broadband seismometer and an STS-1 broadband seismometer, which have been recently used for much broader frequency range in the field of global seismology, in order to observe microtremors for the broadet frequency range (0.03 ~ 10 Hz). The simplest way with spectral analysis requiring only two seismometers was adopted in our observation because we tried to check the advantage of the portability and easy installation of an STS-2 seismometer and to ascertain the usefulness of broadband data to estimate the dominant site characteristics.

We conducted observations at six locations in the Tsukuba area, Ibaraki, Japan, as our test site because of its clear transition from the basement (Mt.Tsukuba) to a thick sedimentary basin (the Kanto plain) and the existence of tall buildings in this area. In this paper, we discuss dominant site characteristics in this area and the potentiality of broadband seismometers for microtremor observations. We do not, therefore, expect more detailed discussions of the underground structure but emphasize on implications of broadband observation with STS-2 seismometer.

II. Observation

We conducted the observation of microtremors at six locations around Tsukuba City, Ibaraki, Japan (Fig.1), in July and August, 1991, using an STS-2 seismometer with the sampling rate of 20 Hz. The STS-2, which has three component oscillators (one vertical and two horizontal components) and high vacuity, has only 9 kg weight and the total system is about 50 kg weight and it can be installed on the narrow area (~ 50x50 cm^2). We used a recorder, PDAS100 (with 16 bits A/D converter) with a harddisk of 40 Mbytes and easily defined all parameters, example the sampling rate, the filters and so on, by a personal computer. Since its installation is quite easy and spends little time, it is so useful for microtremor measurements in a short time interval with small cost. At each site, it was easily installed for two days on a concrete base directly connected to the ground surface (Table 1). As the reference site, we used the STS-1 broadband seismometer of Earthquake Research Institute, University of Tokyo (ERI), which records continuously. The STS-1 seismometer is installed inside an observation tunnel on the basement rock at the altitude of about 280 meters on Mt.Tsukuba (TSK; Fig.1). The STS-1 and STS-2 seismometers have the flat velocity response for the wide frequency range from 1/360 to 10 Hz and 1/120 to 50 Hz with a dynamic range of 150 dB, respectively.

The basement of the Kanto Plain around Mt.Tsukuba is exposed, which consists of granitic and metamorphic rocks mainly belonging to the Ryoke Belt. Five other stations are located on the Quaternary alluvials. According to the basement map (Komazawa and Hasegawa,1988) estimated from a gravity anomaly map (Komazawa,1985) and the geological data based on

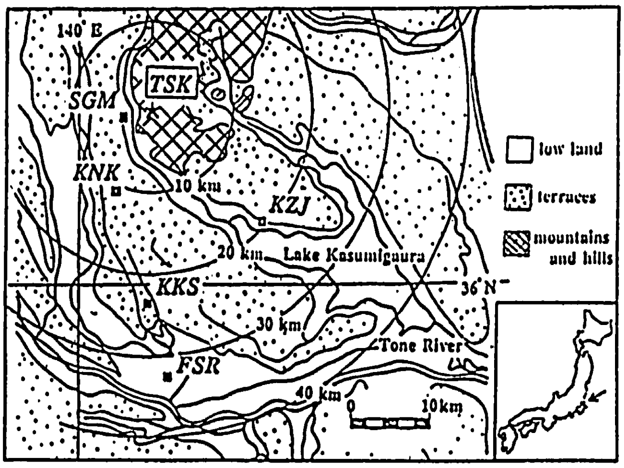

Fig.1 Station locations with gross surface geology (TSK:Mt.Tsukuba, SGM:Sugama, KNK:Building Research Institute, KZJ:Kaizou-ji, KKS:Kukisaki, FSR:Fujishiro-minami).

Table. 1 Summary of Stations

Station Name	Location	Observation Period	Surface Geology	Depth of Basement [m]
TSK	36.21°N, 140.11° E (280 m high of Mt.Tsukuba)	1991.7.15~7.17	Basement rocks	----------
SGM	36.20° N, 140.08° E (Western foot of Mt.Tsukuba)	1991.8.10~8.12	Sedimentary layer A	< 250
KNK	36.10° N, 140.05° E (Northwest in Tsukuba City)	1991.8. 7~8. 9	Sedimentary layer B	300 ~ 500
KZJ	36.07° N, 140.27° E (Northern shore of Kasumigaura)	1991.8. 2~8. 4	Sedimentary layer A	500 ~ 750
KKS	35.98° N, 140.10° E (On a terrace near a marsh)	1991.8.13~8.15	Sedimentary layer C	500 ~ 800
FSR	35.89° N, 140.14° E (Low land between the Tone River and the Kokai River)	1991.8. 5 ~ 8. 7	Sedimentary layer D	800 ~ 1000

Note: Basement rocks: Granitic and metamorphic rocks of the Ryoke Belt
Sedimentary layer A: Sediment of back marsh, mud and sand
Sedimentary layer B: Gravel and sand with 20 ~ 50 %
Sedimentary layer C: Gravel and sand with 50 ~ 100 %
Sedimentary layer D: Mud, sand and peaty soil

geotechnical survey with boreholes around Tsukuba area, the shallowest basement depth is about 250 meters at SGM and the deepest is 800 ~ 1000 meters at FSR. The thickness of alluvial layers tends to increase with the distance from Mt.Tsukuba, but no strong lateral heterogeneity is expected in this area, and any one-dimensional model seems to be valid in most cases.

III. Analysis

A. Wave-form Data

We could record stably in 5, 6 ~ 12 hours after the installation of STS-2 seismometer at each site. We only analyzed data obtained from 22:00 to 7:00 of the next day, when artificial human noise is minimum. The lowest amplitudes of velocity at the quietest period are on the average about 60×10^{-8} and 20×10^{-8}m/sec in horizontal and vertical components, respectively, at TSK (Fig.2). In contrast, we observed as much as 1000×10^{-8}m/sec in horizontal and 800×10^{-8}m/sec in vertical at FSR located on alluvials. In general, the amplitude of horizontal components is 1.2 to 2 times larger than that of vertical, and it tends to become larger with the increase of alluvial thickness. Observed amplitudes were changing both temporally and spatially. At FSR, daytime amplitude is 5 to 10 times larger than that of night time, and from 2 to 3 times at five other sites, due to more vigorous human activities at daytime.

B. Spectral Peaks

Figure 3 summarizes velocity spectra of three components at each site, from which we notice several characteristics in the following frequency ranges simultaneously observed by the broadband seismometer:

(1) 0.03 ~ 0.1 Hz: There are no remarkable peaks at each site. The amplitudes at quiet periods are from 10×10^{-8} to 30×10^{-8}m/sec*sec for TSK, SGM and KNK, and from 10×10^{-8} to 100×10^{-8}m/sec*sec for the others.

(2) 0.1 ~ 1 Hz: The following three types of peaks are identified:
1. Type A (● in Fig.3), predominant peaks between 0.2 and 0.3 Hz observed at TSK and SGM.
2. Type B (□), peaks between 0.2 and 0.4 Hz at KNK, KZJ, KKS and FSR.
3. Type C (▲), peaks between 0.5 and 0.8 Hz at KNK, KZJ and KKS.

(3) 1 ~ 10 Hz: We found sharp isolated peaks in the range between 1.2 and 1.5 Hz (Fig.3, ✻). However, since there are no such peaks observed in the data of ERI.TSK in January, 1992, these peaks should be due to any temporary artificial sources during our observation period in July and August, 1991.

C. Amplitude Ratio

We can eliminate the effect of temporal variation of microtremor sources by taking amplitude ratios of the STS-2 data at our temporary stations to the STS-1 data at ERI.TSK recorded continuously.

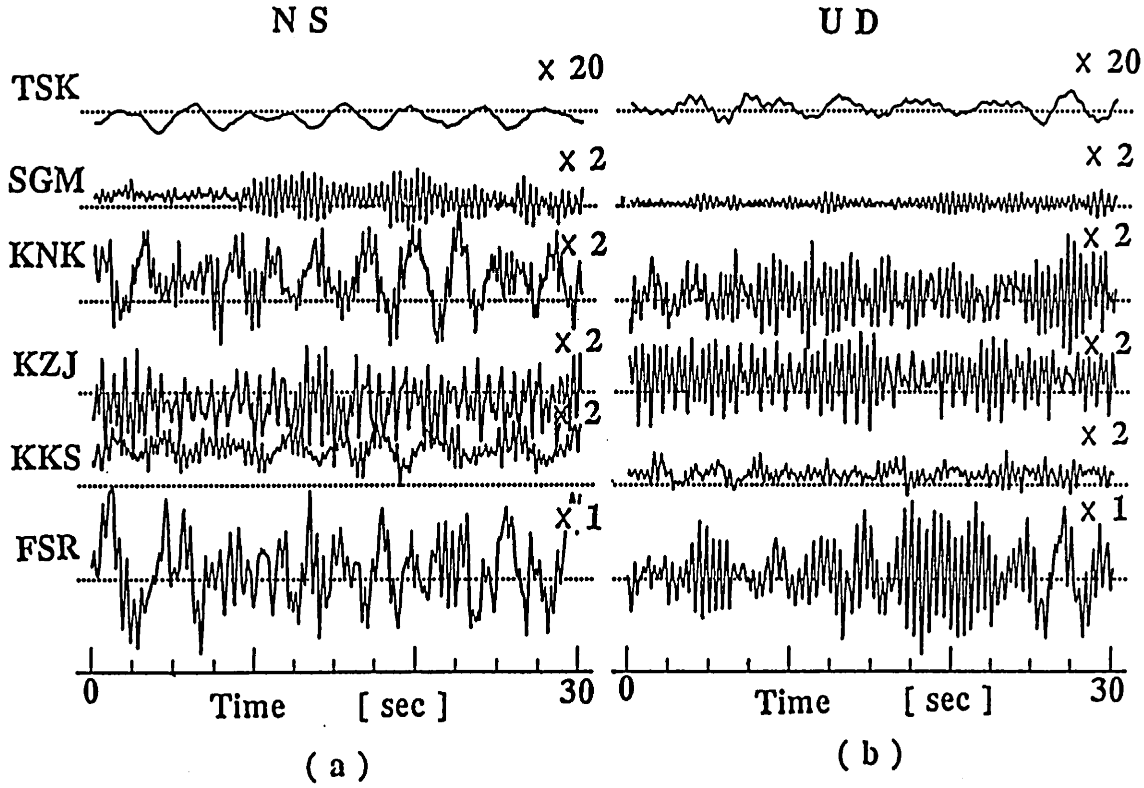

Fig. 2 Velocity seismograms of ERI.TSK (the STS-1 seismometer) and each site (STS-2) for 30 sec at night time when artificial noise is minimum in one day: (a) north-south and (b) up-down components.

We first checked records of the STS-2 seismometer installed at a few meters away from the STS-1 in the observation tunnel of ERI.TSK, in order to compare the response of STS-2 with that of STS-1. The top three figures of Figure 4 show the amplitude ratios of three components. Reliable frequency range, where the amplitude ratio of the STS-2 data to STS-1 at TSK should be unity, is found to be 0.09 ~ 8 Hz and 0.05 ~ 8 Hz for horizontal and vertical components, respectively. The coincidental frequency range between the data of an STS-1 and those of an STS-2 was reported to be wider (> 0.05 Hz in horizontal) with laboratory measurements (Ishihara et al., 1991) than that obtained from our *in situ* observation.

Amplitude ratios in both horizontal and vertical components at all the sites give different values in the frequency range lower than 0.1 Hz. Frequency ranges where the amplitude ratio is mostly unity, that is, the site effect is similar to the rock site (TSK), are between 0.1 and 0.15 Hz and between 0.1 and 0.2 Hz for horizontal and vertical components, respectively. The maximum amplitude ratios are around 7 Hz for SGM (ratios of 10 ~ 20) and from 2 to 4 Hz for the other sites in horizontals, and 2 to 5 Hz for all the stations in vertical. In higher frequency range, the ratio becomes smaller and approaches unity.

D. Cross Correlation

In order to utilize the phase information of our data in addition to the amplitude term, we study the cross correlation of vertical seismograms. Cross correlation functions are calculated for each pair of the reference site TSK.ERI and the other sites of the time-windowed data of 400 sec, which are bandpass-filtered by every 0.1 Hz for the reliable frequency range (0.1 ~ 8 Hz). Figure 5 shows the frequency dependency for the maximum value of the correlation function at each site. The time lag of the time records increases with the frequency: foe example, -0.2 ~ -4.0 sec (0.1 ~ 5.0 Hz) at SGM, -1.4 ~ -5.5 sec (< 1.4 Hz) at KNK and +5.0 ~ -100.0 sec (< 1.2 Hz) at KZJ, which are consistent with calculated wave velocities from the borehole observation, but there are some exceptions such as -1.0 ~ -16.0 sec (> near 1.2 Hz) at KZJ. At KKS and FSR, the time lags are temporally variable in any frequency ranges (e.g., -190 ~ +200 sec for > 0.1 Hz). The correlation tends to become larger for the lower frequency range (< 3.0 Hz), and for the frequency range higher than 3.0 Hz each site shows smaller and similar values. Three-type frequency dependencies which seem to depend on local geological structures can be identified as following:

(1) high correlation values (> 0.8 near 0.1 Hz) even for the higher frequency range up to 2.5 Hz at SGM.

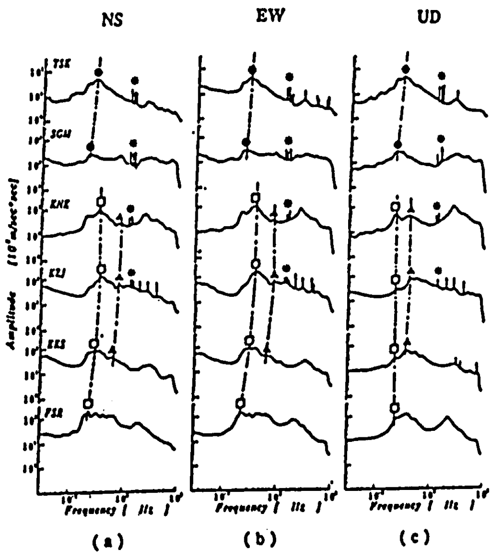

Fig. 3 Velocity spectra at each station: (a) north-south, (b) east-west, and (c) up-down components. Each symbol corresponds to the following peaks: ●:Type A, □:Type B, ▲:Type C, ✱:1.2~1.5 Hz.

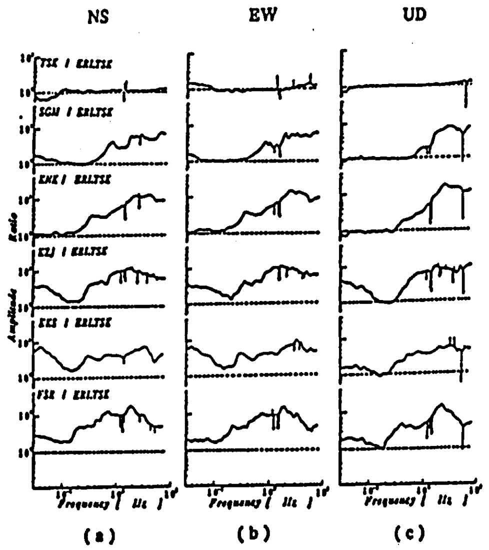

Fig. 4 Amplitude ratios referred to the STS-1 seismometer at ERI.TSK: (a) north-south, (b) east-west, and (c) up-down components.

(2) at KNK, KKS and FSR, correlations value (in high 0.6 near 0.1 Hz) for the lower range (< 0.5 Hz), nearly constant (0.2 ~ 0.3) for the range of 0.5 ~ 1.5 Hz and the minimum (0.1 ~ 0.2) near 2.0 Hz.

(3) the value is locally minimum (~ 0.1) near 1.0 Hz and large (~ 0.2) near 1.5 Hz at most sites, particularly at KZJ.

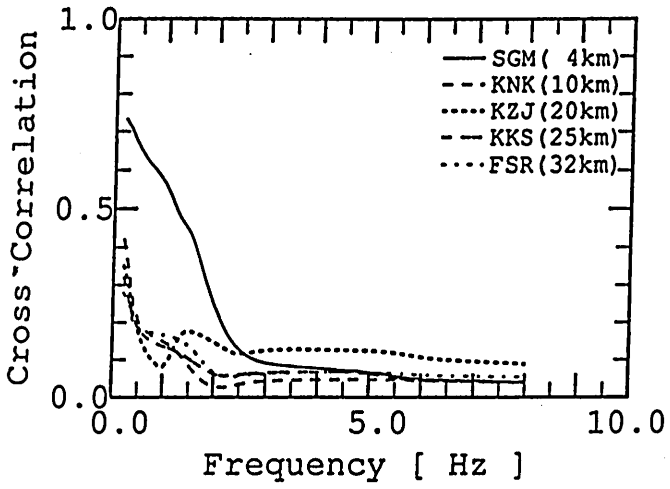

Fig. 5 The frequency dependencies for the maximum value of correlation function of the reference site (ERI.TSK) and the other temporal sites.

For the lower frequency range up to 1.0 ~ 1.2 Hz and higher range (> 2.5 ~ 4.0 Hz), the time variation of maximum value is so small in contrast to those for the frequency range of 1.2 ~ 2.5 Hz where the night time values are 2 ~ 2.5 times larger than those of daytime. These time variation may depend on the changing of source characteristics of microtremors: during night these should have been any particular sources radiating mainly 1.2 ~ 2.5 Hz waves in this area, while the sources are rather random in daytime.

IV. Discussions

Since microtremor sources are variable in space and time, it is not appropriate to assume that all incident spectra are constant at any place. Studies of microtremors have been developed mainly about two categories, short-period (< 1 Hz) and long-period (> 1 Hz) microtremors. Since our observation covered both high and low frequency ranges simultaneously, we discuss the site characteristics of microtremors for above two frequency ranges.

A. The characteristics of microtremors for the lower frequency range (< 1 Hz)

Since maximum values of correlation function of the reference site (ERI.TSK; rock site) and each sedimentary site have little temporal variations and the amplitude ratio of the STS-2 data to the STS-1 data are very similar during each period at night for our analyses, the ratio of the incident spectra between the reference site and each site may be nearly constant. And since the time lags of correlation were little changing in time for the frequency range lower than about 1 Hz at SGM, KNK and KZJ, it may be considered that the arrival direction of the waves for this range (< 1 Hz) were nearly same at these sites. From both our analyses and the result that the ground motions for the frequency lower range than 1 Hz are generated mainly by sea-wave and wind

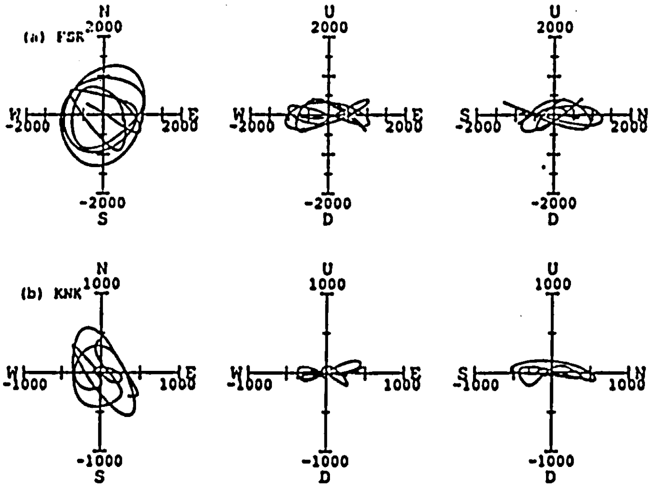

Fig. 6 Particle motions of each pair of components bandpassed with two frequency ranges, (a) 0.2 ~ 0.3 Hz with 20 sec length and (b) 0.7 ~ 0.8 Hz with 10 sec, corresponding to the spectral peaks of Type B (at FSR) and C (At KNK), respectively.

(Kobayashi,1989; Darbyshine,1990), the source of microtremors for this range (< 1 Hz) may be considered to be nearly common among six temporal sites in this study located at the distance shorter than 40 km from the Pacific Ocean or Lake Kasumigaura although the incident spectra for the lower frequency range cannot be assumed to be white or near white and stationary in time indiscriminately (Kagami, 1989).

It is well known that a dominant peak depends greatly upon the ground structure after 1960s (e.g., Kanai,1961). Three dominant peaks were observed in the frequency range of 0.1 ~ 1 Hz and we preliminary interpret these peaks with the following simple models. The peak frequency of type A seems to become lower as the distance from Mt.Tsukuba increases and the correlation value for this frequency range (0.2 ~ 0.3 Hz) are very large (~ 0.8). Assuming the S wave velocity (β) near 0.3 Hz is 3.3 km/sec, the corresponding wave lengths are about 11 km. Since there are almost no or the negligible sedimentary layer at SGM which is located at the distance of about 4 km from ERI, these values seem to be plausible and we interpret these shifts with the two dimensional ridge effect of a mountain studied by Bard (1982) (Fig.7a). Bard (1982) showed that the peak frequency at the mountain is higher than that at the foot because of some resonance effect of the mountain. If we assume the width of Mt.Tsukuba ($2l$ in Fig.7a) is 6 km, its height (h) is 0.8 km, and the SH wave velocity (β) is 3.3 km/sec, peak frequencies are estimated to be about 0.28 Hz for TSK and 0.2 Hz for SGM, which grossly agrees with our observation.

The peaks of types B and C are found to be shifted towards lower frequency as the thickness of alluvial layers increases. For the frequency range of 0.2 ~ 0.3 Hz (type B) and 0.5 ~ 0.8 Hz (type C), the maximum value of correlation function of each type are almost same as shown in Fig.5. The similar values of different sites may depend on little heterogeneity of underground corresponding the reflect waves for each frequency range. The particle motions at KNK and FSR for above frequency ranges (Fig.6) show that both type signals seem to be nearly Love-type waves. We interpret that they are probably caused by any vertical resonance in sedimentary layers since the surface wave propagation and the vertical resonance are nearly coincident if the sediment velocity is very low. The peaks of type B are interpreted with the vertical resonance of the entire sedimentary layer between the surface and the top of bedrock. Figure 7b shows the resonance model in which S wave velocity (β) of the sedimentary layer, estimated by the velocity (α) structure of P wave (Hasegawa et al., 1987), is 0.8 km/sec (assuming $\beta/\alpha=0.44$). Thickness of the layer turns out to be about 900 meters, which agrees with the basement depth given in the basement map. On the other hand, the higher frequency peaks of type C seem to be related to much thinner and softer surface layers. Figure 7c shows the model in which we assume S wave velocity of the soft layer is 0.6 km/sec, estimated from the sediment-basement system using borehole data (Kinoshita, 1988). We get the depth of reflection surface to be about 200 meters, which agrees with the structure obtained from reflection experiments in the eastern foot of Mt.Tsukuba (Yokokura et al.,1985).

B. The characteristics of microtremors for the higher frequency range (> 1 Hz)

The incident spectra of short-period microtremors have been assumed nearly white in any place and time (Kanai et al.,1961) or considered that its spectra have frequency dependency. Kobayashi (1989) concluded that microtremors for the frequency range higher than 1 Hz are caused by artificial activities. We can find the maximum values of correlation function are temporally variable for a particular frequency range (1.2 ~ 2.5 Hz) in contrast to small or negligible change for the range higher than 2.5 ~ 4.0 Hz with random incident directions. We, therefore, find these temporal change may depend on human activities and ground motions by human activities seem to vary significantly in time for the frequency range of 1.2 ~ 2.5 Hz in this area and our observation period.

Although five temporal sites were located at the distance up to about 35 km from the reference site and the distance between both sites may be thought to be unuseful as an array observation and we cannot clarify the arrival direction of incident waves to each site for our two temporal sites observation, Fig. 5 shows us a meaningful correlation for the frequency range up to 2.5 Hz between ERI.TSK and the other sites. We find the remarkable correlation among ERI.TSK and SGM up to near 2.5 Hz. Assuming the S wave velocity (β) near 2.5 Hz is 0.3 km/sec, the corresponding wave length is about 0.12 km. The changes of maximum value of correlation function of ERI.TSK and KNK, KKS and FSR for the higher range (> 1 Hz) behave similarly. It may depend on heterogeneities of the similar size in the underground structure. We can find the behavior of KZJ is quite different from those of the other sites for the frequency range of 1.0 ~ 1.5 Hz. Although the more dense-array observation is required in order to identify the site characteristics, since the large correlation near 1.5 Hz is unstable in time while small but stable near 1.0 Hz, the former may reflect the source characteristics rather than the

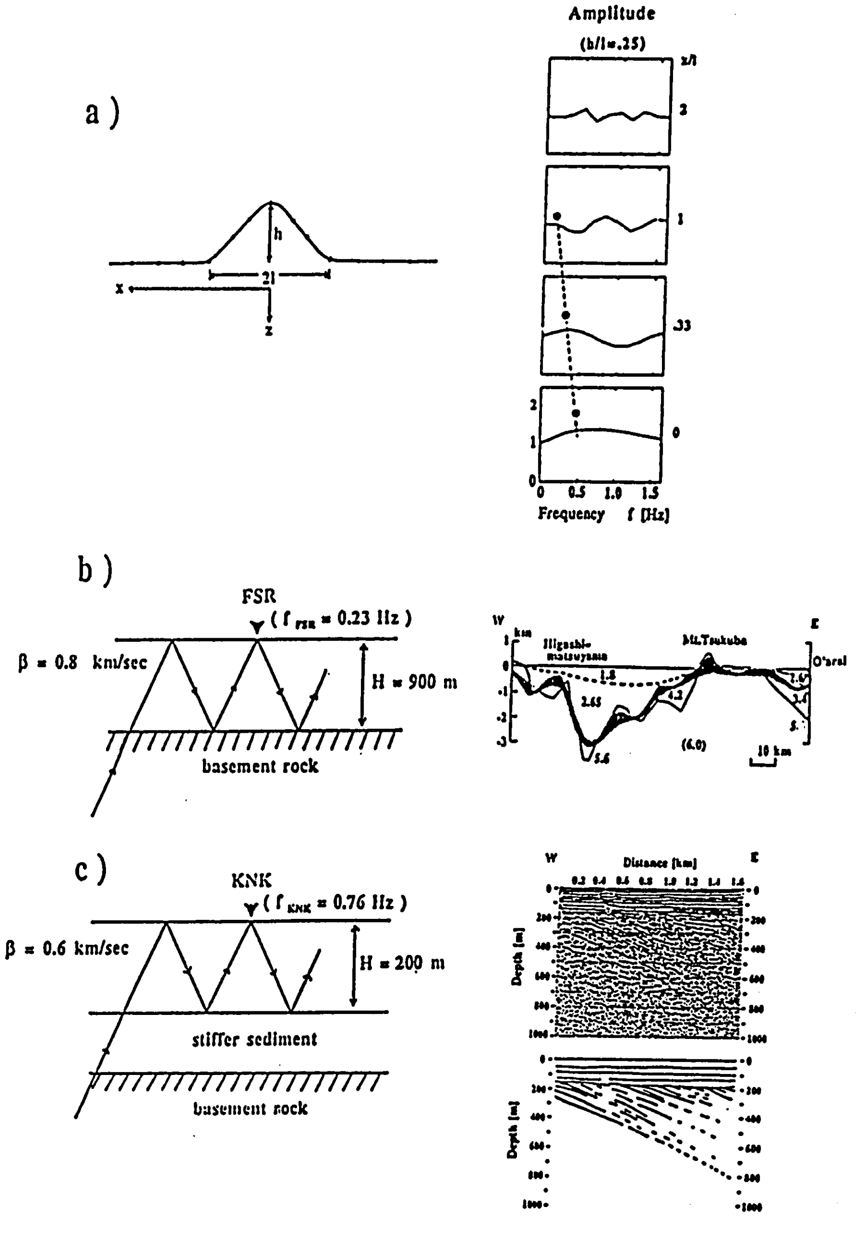

Fig. 7 a) Two-dimensional ridge effect of a mountain (after Bard, 1982): Mountain model where $2l$ is the mountain width, h is the mountain height, and x is the distance from the center of the mountain, respectively. Spectra with h/l (i.e., the height of the mountain) value of 0.25 for each x/l value (i.e., the distance from the center of the mountain). Note that the peak frequency (shown by ●) is shifted towards lower frequency as the distance from the mountain increase.

b) Particle motion at FSR are interpreted with Love-type wave. Vertical resonance model with a sedimentary layer between the surface and the top of the bedrock for the peak frequency of 0.28 Hz observed at FSR with the velocity structure of P wave (Hasegawa et al., 1987).

c) Particle motion at KNK are interpreted with Love-type wave. Vertical resonance model with a layer shallower than the bedrock for the observed peak frequency of KNK (0.76 Hz) with the structure obtained from reflection shows raw data and the bottom is redrawn schematically.

underground structure and the latter depend directly upon the underground structure.

The amplification factor observed on general basement rock in the frequency ransedimentary layers is larger than that observed on the ge lower than about 5 Hz, basement rock in the frequency ransedimentary layers is larger than that observed on the ge lower than about 5 Hz, both merge around 5 Hz, and finally the amplification factor of the basement rock becomes larger above 5 Hz, as reported in many areas over the world (Aki, 1988). We, however, found no such higher amplification at the basement rock site in our data even in the frequency range higher than 5 Hz. Since the decrease of amplification factor of sedimentary layers in higher frequency is caused by any intrinsic absorption of soft sediments, the above observation implies that the sedimentary layers around the Tsukuba area are harder than other areas.

V. Conclusions

We analyzed the microtremor data observed in the Tsukuba area for the reliable frequency range between 0.09 and 8 Hz in horizontal components and between 0.05 and 8 Hz in vertical component, to check how useful the STS-2 broadband seismometer is with microtremor observations. Microtremor observations for a broadband frequency range provide us many informations under the same observation conditions and they are useful for investigating the changing factors of site and source characteristics in time and space although in the field of earthquake engineering the measurements might be required for a narrow range particularly. We used a simple method and discussed only dominant features of our observation, while more precise geological and seismological descriptions of underground structure require studies based on dense-array and/or borehole observations. The following site characteristics are revealed:

(1) For the lower frequency range than 1 Hz, the source of microtremors are nearly common among our six temporal sites in Tsukuba area from the measurement of cross correlations between two sites. For the higher frequency range than 1 Hz, particularly 1.2 ~ 2.5 Hz, the source characteristics of microtremors are variable in time.

(2) Spectral data show some peak frequencies of 0.3 ~ 0.2 Hz at the TSK and SGM sites near Mt.Tsukuba where the thickness of sedimentary layers is negligible. These peaks become lower as the distance from Mt.Tsukuba increases, which may be explained by the topographic high model of Bard (1982).

(3) The peaks for the frequency range of 0.2 ~ 0.4 Hz observed at alluvial sites are explained by vertical resonance in a soft layer between the surface and the top of the bedrock. On the other hand, the peaks of 0.5 ~ 0.8 Hz seem to be related to any shallower soft surface layer. These models are consistent with some geological information in this area.

(4) Taking amplitude ratios with respect to the rock site for the range higher than 5 Hz, we found the sedimentary layers in the Tsukuba area are harder than in most of other sedimentary areas.

The broadband data informed us the reasonable results with the other geological and seismological informations by even a simplest method. We cannot always persist that a broadband microtremor observation is more useful than any other observation method. However, from our interest in the field of basic seismology, we have found that the observation using a portable broadband seismometer such as an STS-2 gives us more information of longer and shorter period ground motions by stable response, which reflects the characteristics at the deeper and shallower geological and seismological structure, simultaneously under the same observational conditions by an easy installation. We, therefore, expect more detailed array observations of microtremors using broadband seismometers to become popular in future.

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We thank Minoru Takeo and Tadao Watanabe (Earthquake Research Institute) for providing us with the STS-1 data recorded at ERI.TSK, Shigeo Kinoshita (National Research Institute for Earth Science and Disaster Prevention) for some seismological information of the Tsukuba area. We also appreciate the cooperation of those who offered us five temporary observation sites.

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