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Assessment of site effects on seismic input motions in the Sapporo urban region, northern Japan, utilizing long-period microtremors

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ABSTRACT: Intensive measurements of long-period microtremors were conducted in Sapporo, northern Japan, in 1990 and 1991 following a preliminary measurement of 1985. Records were obtained at 183 stations covering the 40 km x 40 km area of Sapporo metropolitan. Spectral ratios at four periods of interest were plotted onto maps and contoured by the automatic drawing technique. These maps were compared with geological maps, and some correlations were found.

INTRODUCTION

When designing high-rise buildings or large building structures with long fundamental periods, the information about deep soil deposits upon which they are planned is necessary for the assessment of seismic ground amplification. We have been conducting a series of studies for the investigation of geological features at relatively deeper soil deposits, using long-period microtremors. The study areas cover the Niigata plain, Japan, in 1977 (Kagami et al., 1982); the San Fernando Valley, California USA, in 1978 (Kagami et al., 1986); the Perth Basin, Western Australia, in 1989 (Kagami et al., 1991); and the San Francisco Bay Region, California USA, in 1990 (Dravinski et al., 1991). Since 1985 we have conducted long-period microtremor observations in Sapporo urban area (Ishikari Alluvial Plain), northern Japan, and obtained spectral ratio contours for seismic zonation. The results from the observations are presented here.

OBSERVATION SITE

Sapporo (Figure 1) is the capital of Hokkaido island, northern Japan, with a population of over 1.7 million. As the center of commerce and administration of the island, Sapporo is expanding rapidly and engulfing a number of its satellite cities around, making themselves a large commercial center. Seismic assessment of Sapporo is therefore important, and the project is under way to investigate its underlying, shallow-to-deep ground conditions in terms of seismic amplification.

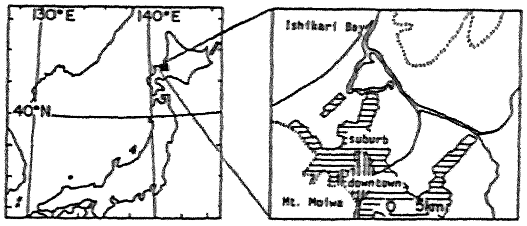

Figure 1. Location map of Sapporo urban area.

Seismicity around Sapporo is relatively high. In the last quarter century intensity V on Japan Meteorological Agency (JMA) scale, or MM VIII, was recorded twice in Sapporo. Figure 2-(a) shows the intensity microzoning map of Sapporo during the 1968 Off Tokachi earthquake of M.7.9. A large number of slight-to-moderate damage was reported, although the city is located about 200 km away from the epicenter. Such susceptibility to earthquakes can be attributed to the underlying thick sediments (Ishikari Alluvial Plain). Intensities felt in the region ranged between III and V, showing that ground motion amplification differed with soil conditions. Strong motion records in Fig. 2-(b) also indicate the influence of ground conditions at stations.

When the 1982 Off Urakawa earthquake of M 7.1 occurred, Sapporo again suffered a number of damage with intensities ranging up to JMA V. At this time a detailed intensity microzoning map of Sapporo was obtained from a densely-distributed intensity questionnaire survey (Kagami et al. 1988).

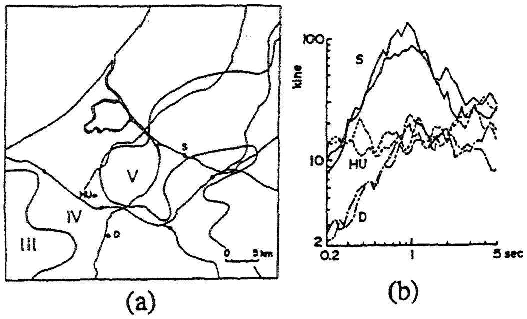

Figure 2(a) Intensity distribution map of Sapporo during the 1968 Off Tokachi earthquake (on JMA intensity scale).

(b) Strong motion records at three stations in Sapporo during the 1968 Off Tokachi earthquake.

Geological information is sufficient for the shallow soil deposits but rare for the deep ones in the region. Geological maps and boring data are available and yet are only useful for estimating the ground amplification for short period below 1 second. Figure 3(a) shows depth in meters to the thickness of surface deposits. In sharp contrast, the deep soil information, which is responsible for the amplification of period 1-10 seconds, is only available in terms of soil profiles at several deep oil drilling sites. Some part of deep soil structure estimated from limited geological data is shown in Fig. 3(b). For the accurate evaluation of long-period (1 to 10 seconds) ground amplification, observations of long-period microtremors should be conducted at sufficient number of points.

PLAN FOR MICROTREMORS OBSERVATION

The observation area was chosen as in Fig. 4. Nine traverses were carefully planned: for seven traverses, deployment of instruments were chosen to be in a southwest-northeast orientation to reduce attenuation problems as at least for the longer period end of the spectrum, the source distance (from Ishikari Bay to each of the site), was similar. The other two traverses were chosen to be in a northwest-southeast orientation to see the attenuation influence of microtremors. Each traverse was about 30 km long, and the deployment of instruments was planned at intervals of about 1-2 km. The area of about 40 km x 40 km covered 183 stations.

In order to minimize changes in environmental conditions, simultaneous measurements for each traverse are necessary. A reference station was therefore set up at Hokkaido University (HU) where microtremors were continuously recorded throughout the period during which recordings for traverses were under way.

When measuring microtremors, noises from traffic or industrial sources are often critical to the quality of records. Monitoring subsystem was added to the equipment that allows us to see on the spot whether an obtained record is good enough or not. The block diagram of the equipment used and the flow chart of data processing are shown in Figure 5. An approximate sensitivity curve for the system is given in Figure 6. The system consists of a force balance type velocity seismograph with high resolution, an amplifier system with maximum gain of 80 db, and a lap-top type computer capable of recording the wave forms of records and their spectra in the field. A portable system, that can be carried in the trunk of a compact car, is operated with an external 12 VDC power supply unit.

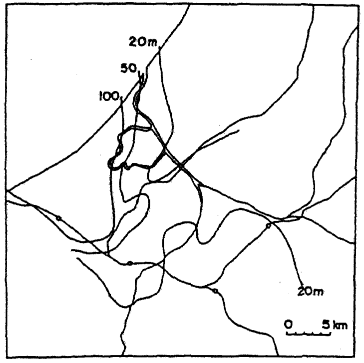

Figure 3(a) Depth in meters to the thickness of surface deposits.

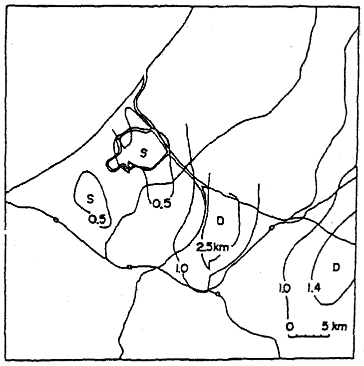

Figure 3(b) Depth in meters to the base of the Pliocene.

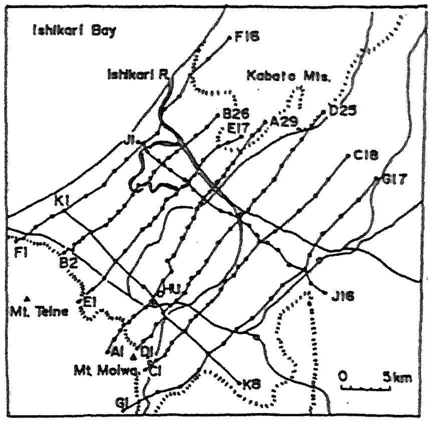

Figure 4. Location of traverses and the sites occupied.

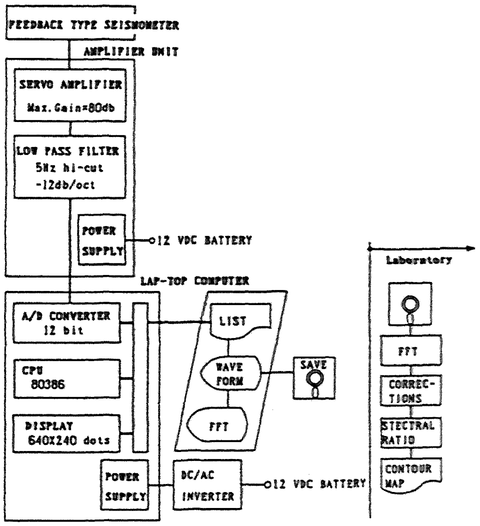

Figure 5. Block diagram of microtremors observation system and the flow chart of data processing.

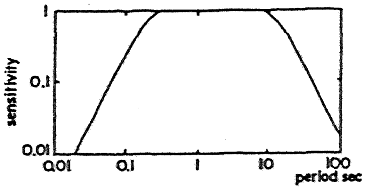

Figure 6. Overall characteristic of observation system.

OBSERVATION AND ANALYSIS

Recordings were carried out over years; for traverses A, B, and J in September 1985; for C, D, E and J in August 1990; for K, J, F and G in July 1991. Figure 7 shows the fluctuations in the amplitude of recorded microtremors at the reference station (HU) during the observation periods. The time difference in amplitude is quite large: the highest spectra being 10 times the lowest. This was mainly due to the perturbations caused by an approaching typhoon.

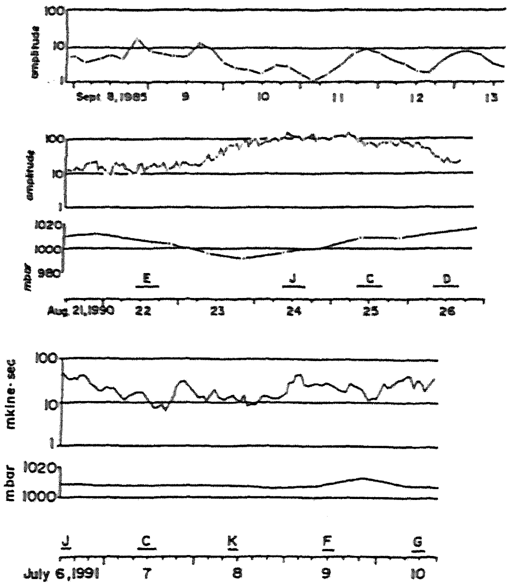

Figure 7. Time variation in maximum amplitude of spectra of microtremors at the reference station (HU) and atmospheric pressure.

Examples of time-domain records and their Fourier spectra are shown in Figure 8(a). These records were obtained at stations C1, C5, and C11. Each curve has predominant peaks between the period range of 2 and 4 seconds. Notice that the curves have similar shapes and predominant peaks at around the same period range of 2-4 seconds, although the ground amplification varies largely with the site conditions of station. The fact that there are for each curve many predominant peaks with similar heights at the period 1-4 seconds suggests that there exists no clear seismic basement that usually would generate a predominant unipolar peak in Fourier spectra because of its high velocity contrast between the basement and its upper layers.

Figure 8(b) shows Fourier spectra for each station of traverse line D, arranged in order from southwestern most (D1) to northeastern most (D25). We can see how the maximum amplitude changes along the line D.

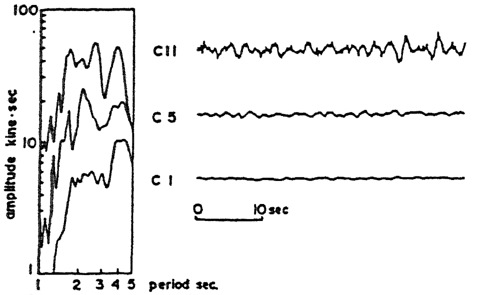

Figure 8(a). Examples of wave forms of microtremors and their spectra.

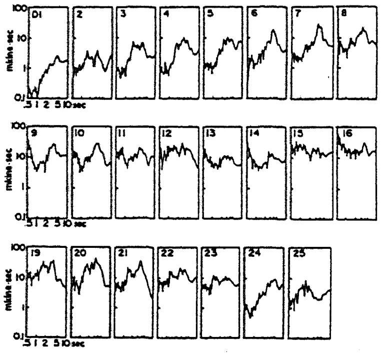

Figure 8(b). Spectra along the line D.

In figure 9, the maximum amplitude (period 0.5-4 sec) of spectra recorded on the traverse line J in 1985, 1990 and 1991 is plotted. These curves show similar trends providing the confidence in the stability of the spectra. Spectral amplitude of long-period microtremors in this region therefore can be characterized in terms of site-specific geological conditions related to a period ranging from 2 to 4 seconds.

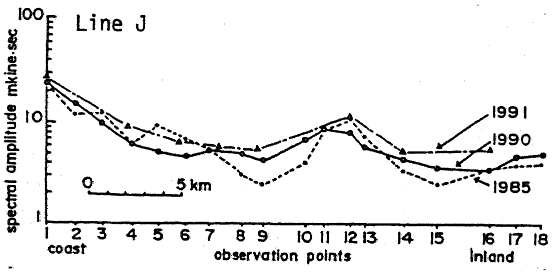

Figure 9. Spectral amplitude observed in 1985, 1990 and 1991 along the traverse line J.

The maximum amplitude of spectra recorded on the traverse lines C and D is plotted in Figure 10. Recordings for line C were conducted in 1990 and 1991. In the 1990 measurement, recordings were suspended at half way as shown in Figure 10(a), because of instrumental problems. The recordings were then recovered in the following year. Notice again the similarity of the trends of the two curves. This confirms the repeatability (stability) of records and reflects geological features: low amplitude corresponds to shallow soft sediments (stations 1 and 2, for instance, are located at the base of Mt.Moiwa); and high amplitude to thick soft sediments.

The shape of the curve for line D (Figure 10(b)) is similar to that for line C. As the lines C and D run in parallel with only a few km of distance, it is understandable that the trends are similar.

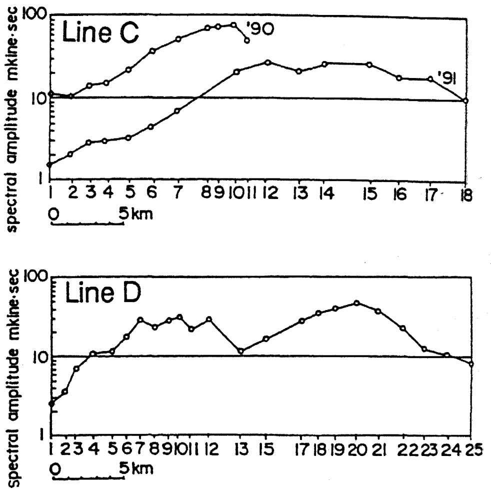

Figure 10 Maximum amplitude of spectra along the lines C and D.

TWO DIMENSIONAL AMPLIFICATION CHARACTERISTICS IN THE SAPPORO URBAN REGION

Spectral ratios over the period range of interest (2-4 sec) were obtained for each site by dividing the Fourier spectra by the corresponding spectra at the reference site (HU). In Figure 11 spectral ratios at periods of 0.5, 1.0, 2.0, and 4.0 are shown for the lines C and D. Overall trends of the curves are similar for all the periods. Fluctuations for the period 0.5 tends to be larger than the others. For the line C, recordings were made twice in 1990 and 1991, and the repeatability of the records are suggested in the figure.

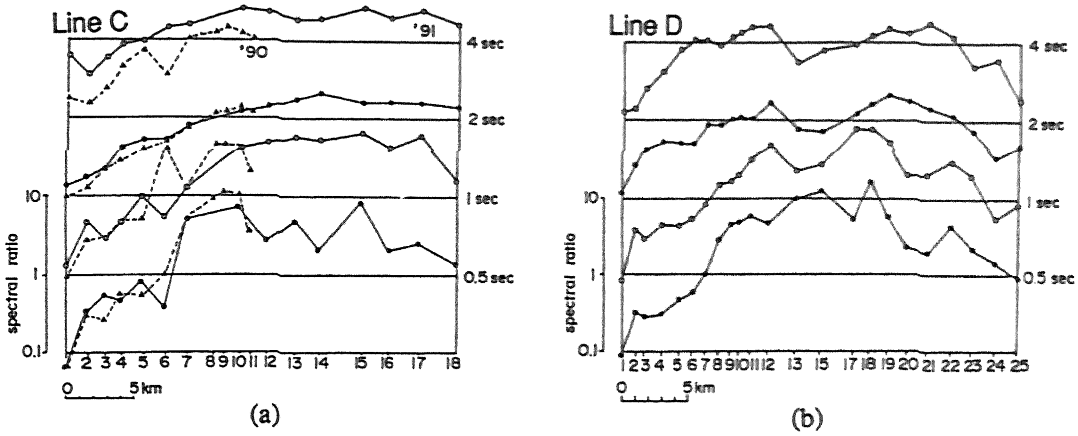

Figure 11.Spectral ratios at periods of 0.5, 1.0, 2.0, and 4.0 along the line C and D.

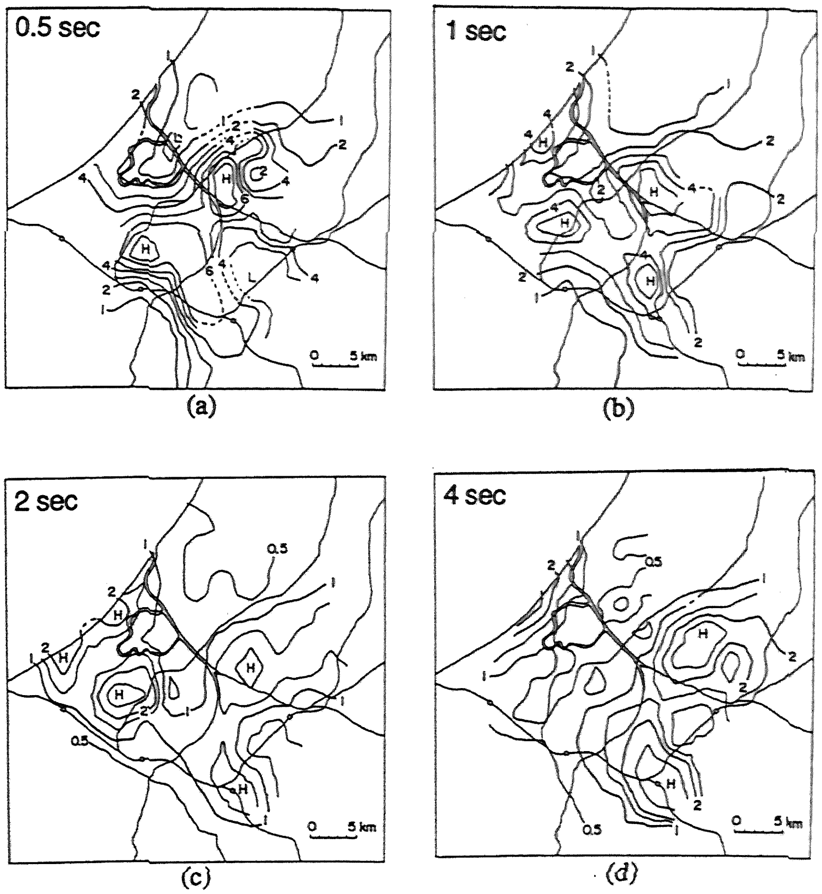

Figure 12. Zoning map of spectral amplitude ratio of microtremors for periods shown; H and L showing high and low amplification.

In Figure 12 spectral ratios at periods of 0.5, 1.0, 2.0, and 4.0 are plotted and contoured by the automatic drawing technique (Ohta and Kagami, 1982). The tendency is that spectra ratios decrease toward the left bottom corner and right upper corner of the maps where hilly topographies become predominant. The locations of higher (H) or lower (L) values, however, differ with the period concerned. These maps should be compared with geological maps (Fig. 3). The shallow soil deposit map (Fig. 3(a)) can be compared well with spectral ratio contours of 0.5 second period (Fig 11 (a)). Contours of 1 or 2 spectral ratio correspond well with the deep soil deposit contour map (Fig. 3(b)).

CONCLUSIONS

Intensive measurements of long-period microtremors were conducted in Sapporo urban area in 1990 and 1991 following a preliminary measurement of 1985. Spectral ratios were obtained for 183 stations covering the 40 km x 40 km area of Sapporo metropolitan and plotted onto maps and contoured by the automatic drawing technique. These maps were compared with geological maps, and some correlations were found.

One of new aspects of this study was the day-time measurement in the midst of urban noise sources. The equipment was upgraded in both terms of hardware and software. This advancement in the equipment was found to ease the entire process of recording microtremors.

In order to establish the relation between spectral ratios and seismic ground motions, accumulation of microtremor measurements should be encouraged.

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