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SITE RESPONSE CHARACTERISTICS OF SEISMIC STATIONS IN JAPAN BASED ON MICROTREMOR OBSERVATION AND STRONG MOTION RECORDS

Jun Saita[1], Masahi Matsuoka[1], Fumio Yamazaki[1] and Khosrow T. Shabestari[1]

ABSTRACT : Recently in Japan, the National Research Institute for Earth Science and Disaster Prevention (NIED) has installed many strong motion accelerometers and built new networks. One of the networks is named "K-NET" with about one thousand instruments placed on the ground surface, and the other is named "KiK-net" with about four hundred sets of instruments installed both on the ground surface and in the boreholes. NIED has made available all the strong motion records together with the soil data of all stations. The site response characteristics can be derived from the "K-NET" and "KiK-net" strong motion records using the horizontal to vertical (H/V) Fourier spectrum ratios. Microtremor observations were conducted at the seismic stations in Hyogo prefecture, located in the center of Japan, mainly at "K-NET" and "KiK-net" stations. These stations have recorded many earthquakes with a wide range of magnitude. The H/V ratios of microtremor were compared with those of strong motion records of "K-NET" and "KiK-net", and they showed similar values. The H/V ratios of microtremor were also compared with the geomorphological and geological conditions. Although the H/V ratios have wide variation even in the same soil category, they appeared to exhibit some similarity for the same group. To estimate the distribution of strong motion indices, it is very important to know the geomorphological and geological conditions. For this objective, the H/V ratio of microtremor may be a good tool for classifying the site amplification characteristics.

KEYWORDS: Site response characteristics, seismic stations, strong motion records, microtremor observation, H/V spectrum ratio.

1. INTRODUCTION

Hyogo prefecture in the central Japan has developed the "Phoenix Disaster Management System", which is utilized, in normal situations, for exchanging information with residents and local jurisdictions, and, in the event of disasters, will support prompt emergency response activities [1]. The instrumental seismic intensities from 97 stations of the seismic network of this system will be used to grasp the distribution of the seismic intensity in the prefecture immediately after the occurrence of an earthquake.

It is also important to estimate the strong ground motion distribution in the seismic design and retrofit of structures. However, the strong motion distribution is highly affected by local soil conditions, and hence the evaluation of local site effects is necessary. Hence in this study, microtremor observations were conducted at 116 seismic stations in Hyogo prefecture. The H/V Fourier Spectrum ratios of microtremor are compared with those of strong motion records. The H/V ratios of microtremor are further compared with the geomorphological land classification and the method to evaluate site response characteristics using available data is sought.

[1] Earthquake Disaster Mitigation Research Center (EDM), NIED, Japan

2. ESTIMATION OF JMA SEISMIC INTENSITY DISTRIBUTION

The strong motion distribution can be estimated using the attenuation relations considering the site-specific term [2]. The site-specific term, called the station coefficient, represents the site amplification characteristics of the recording station. Yamazaki et al. [3] obtained the averaged station coefficients for 11 soil classifications from 77 Japan Meteorological Agency (JMA) stations based on their geomorphological classification and subsurface geology. From the averaged station coefficient for each soil class, the site amplification ratios for the strong motion indices were obtained, taking mountain in the geomorphological classification as the reference. Then, the amplification ratios can be estimated by 1km x 1km pixel throughout Japan, using the geomorphological and subsurface geological data in the Digital National Land Information (DNLI).

Kriging technique [4], a method of stochastic interpolation, is employed to estimate the spatial distribution of ground motion indices from recorded values. In Kriging technique, the observed values are realized at the observation points. Between the observation points, stochastic interpolation consisting of the trend (mean) and random components gives an estimation of the spatial distribution.

Since the earthquake motion on the ground surface is affected by the amplification characteristics of surface layers, the interpolation should be carried out at the (outcrop) base level, as shown in Figure 1. The amplification ratio mentioned above is used to convert the values recorded on the ground surface to those at the base level. After completing the spatial interpolation by Kriging, the amplification ratio is again introduced and the spatial distribution of the ground motion indices on the ground surface is obtained.

The Tottoriken-Seibu Earthquake occurred on 6 October 2000 with moment magnitude Mw = 6.6. The hypocenter was 35.275 N and 133.35 E with depth of 11.0 km. For this earthquake, 329 of K-NET and KiK-net records were used to estimate the spatial distribution of the JMA seismic intensity. Amplification ratios at the recording sites were estimated from the topography and subsurface soil classification of the DNLI. Using these amplification ratios, the values recorded on the ground surface were converted to those at the base level. Using the converted values at the base level, the simple Kriging method was employed to estimate the spatial distribution of the strong motion indices at the base. In this study, attenuation relations for strong motion indices were used as the trend component of Kriging. Since the attenuation relations contain inter-event variability (deviation associated with different earthquakes), it may be preferable to construct an attenuation equation for each event if many observed values exist. Using the converted observed values at 329 sites whose soil conditions had

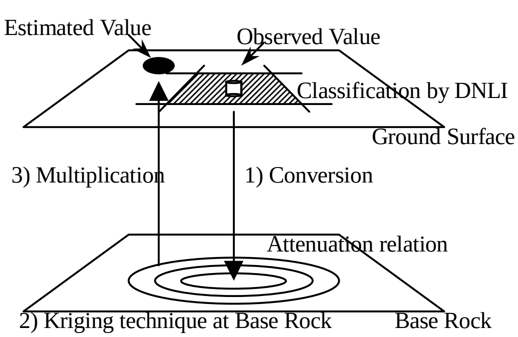


Figure 1. Schematic figure for Kriging technique.

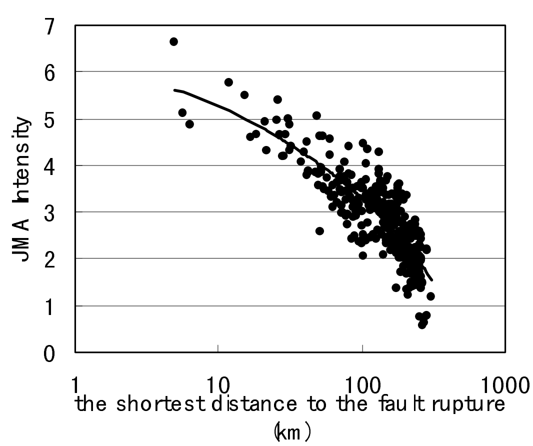


Figure 2. Attenuation relationship of JMA intensity.

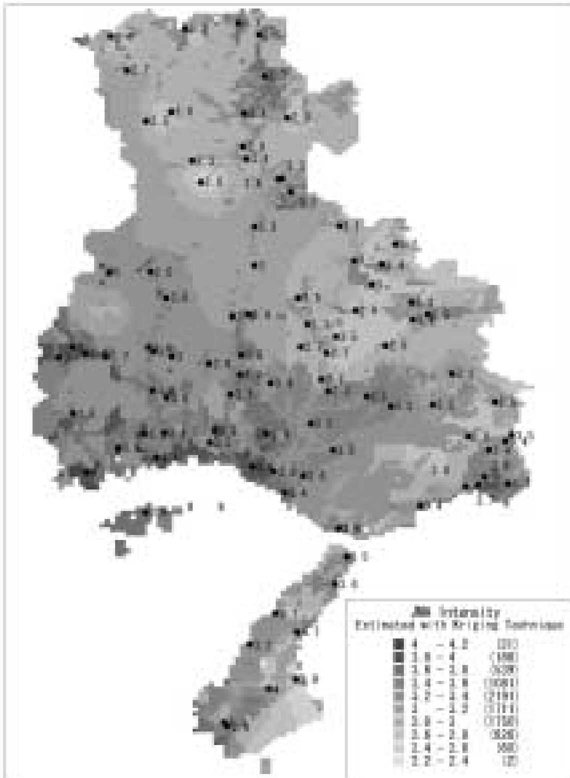


Figure 3. Distribution of JMA intensity on ground

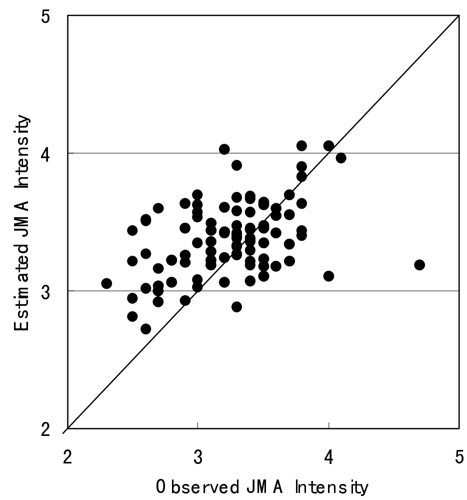


Figure 4. Comparison of observed and estimated JMA intensity from the stations of the seismic network of the Hyogo prefectural system.

been estimated, the attenuation relation for the 2000 Tottoriken-Seibu Earthquake at the base [5] is obtained as

$$I_{BASE} = 7.527 - 0.00416r - 1.89\log_{10}(r + 5.0) \qquad (1)$$

where r is the shortest distance (km) to the fault rupture. The obtained relation for JMA intensity is plotted in Figure 2 together with data points.

In Kriging technique, a spatial autocorrelation function should be assigned. An exponential function was employed in this study. The correlation distance, which controls the influence of observed data, was assumed to be 5.0 km. Note that if the correlation distance is large, the estimated distribution connects the observed points irrespective of the trend component, while if the correlation distance is small, the estimated distribution approaches the trend rapidly.

In this study, Kriging technique was employed for the residuals (the converted observed value at the base minus the trend component):

$$X_{Ii} = I_{bi} - I_{mi} \qquad (2)$$

where suffixes b and m represent "base" and "mean", respectively. The simple Kriging was carried out, assuming the residual distributions to be a zero-mean Gaussian stochastic field. Figure 3 shows the estimated spatial distribution of the JMA seismic intensity together with the observed values at the K-NET and KiK-net stations used for Kriging.

Figure 4 shows the relationship between observed and estimated JMA intensities from the stations of the seismic network of the Hyogo prefectural system. In this figure, the estimated values were different from the observed values at some sites. It appears that the soil classification by the DNLI does not always reflect the site condition at the strong motion station.

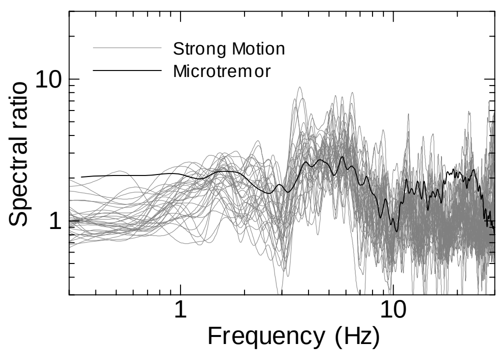
3. MICROTREMOR MEASUREMENT

3.1 Microtremor Measurement and Analysis

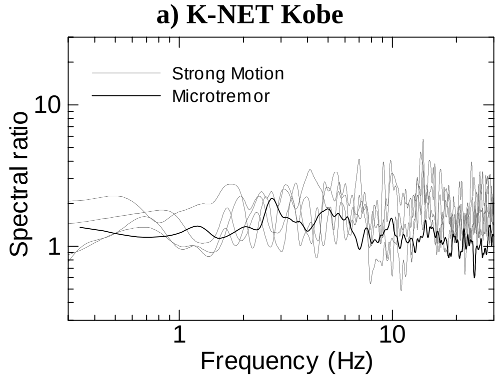
Microtremors were observed at 116 seismic stations in Hyogo prefecture. The instrument used for microtremor measurement was SPC-35N (Tokyo Sokushin Co.). The velocity records obtained by the sensors are high-pass-filtered, amplified and converted to digital recording using a 16-bit A/D converter for storage in the hard disk of a personal computer. For velocity, the sensitivity of the instrument is flat for periods less than 1 second. A sampling frequency of 100 Hz was used. Microtremors were recorded for 32,768 data points (= approximately 5.5 minutes). The records were band-pass-filtered between 0.3 Hz and 30 Hz, and four sets of records with a duration of 20.48 seconds were used in the calculation. The selected sets were converted from the time domain to the frequency domain to obtain the Fourier spectrum, which was smoothed using Hanning window with bandwidth of approximately 0.4 Hz. Then, the horizontal to vertical (H/V) spectral ratios [6] were derived as the averages of the four sets of H/V spectral ratios.

3.2 Comparison between Strong Motion Records and Microtremor

The acceleration records used in this study were observed at 27 K-NET and 12 KiK-net stations from 11 May 1996 to 31 December 2000. The Fourier spectra were calculated for all data of the records and smoothed using Hanning window with bandwidth of approximately 0.4 Hz. Then, the H/V spectral



a) K-NET Kobe



b) K-NET Muraoka

Figure 5. Comparison of the H/V Fourier spectral ratios for strong motion records and microtremor.

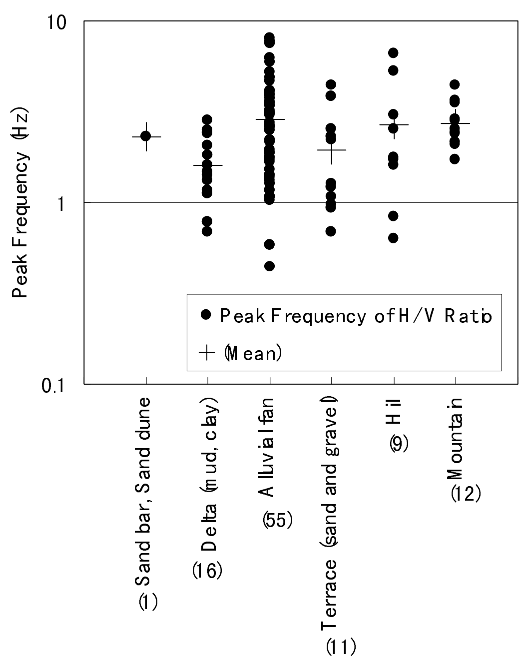


Figure 6. Relationship between the geomorphological classification and the peak frequencies of the H/V spectral ratio of microtremor.

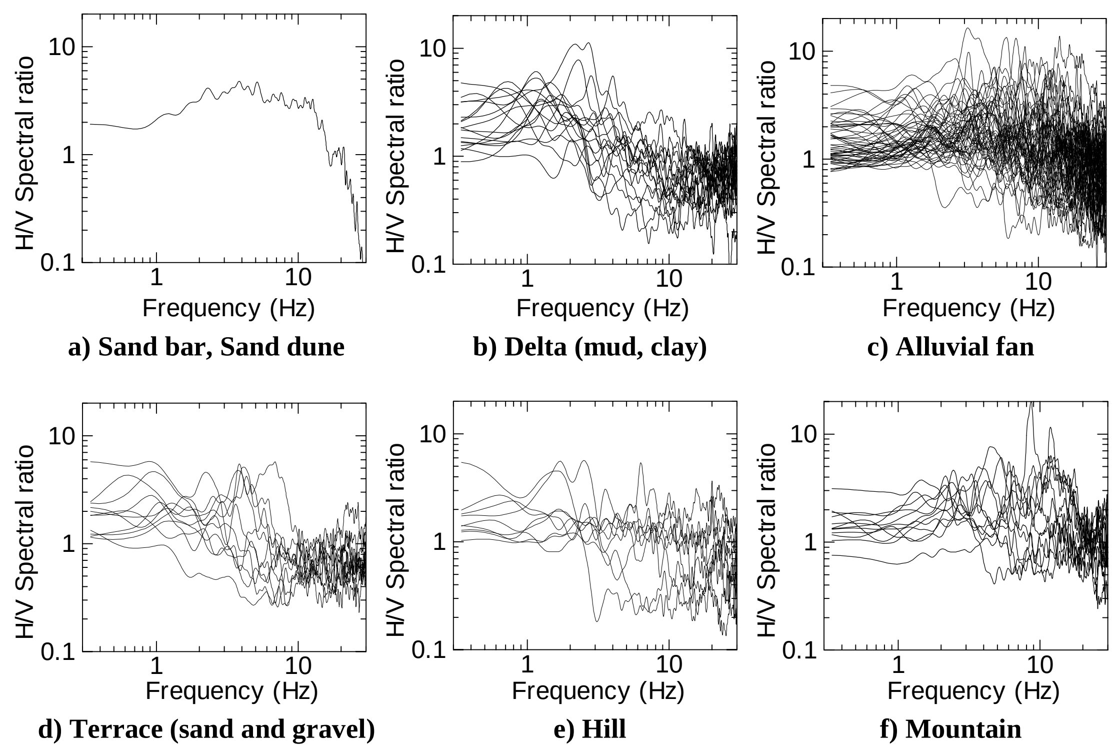
ratios were calculated for both NS and EW components. Figure 5 shows the comparison of the H/V Fourier spectral ratios for strong motion records and microtremor at the K-NET Kobe and Muraoka stations. Figure 5 shows the NS component of the H/V Fourier spectral ratios because there was no significant difference between NS and EW components.

In the figure, the shape and amplitude of the H/V spectral ratio of microtremor at each site are seen to be similar to those for seismic motion. The reason for this similarity can be explained as follows. According to Yamazaki and Ansary [7], the ratio of horizontal-to-vertical (H/V) velocity response spectra for intermediate to far field records is almost independent of the magnitude and source-depth, and source-to-site distance although the horizontal and vertical velocity response spectra are dependent on them. Thus, the site response characteristics can be derived from the H/V spectral ratio. It is also known that velocity response spectrum with zero damping is similar to the acceleration Fourier spectrum amplitude. This indicates that the H/V Fourier spectral ratio of strong motion records represents the site response characteristics. The H/V spectral ratio of microtremor is also commonly used as an index to predict the site amplification characteristic [7].

The soil profile was investigated for all the K-NET stations. Although both Kobe and Muraoka stations have similar profiles of bedrock with a thin surface soil layer, the shapes of H/V spectral ratios are different. This indicates that microtremor measurement is a good tool for detailed investigation of site response characteristics.

3.3 Comparison to Classification of the Site Response Characteristics

Figure 6 shows the relationship between the geomorphological classification and the peak frequencies of the H/V spectral ratio of microtremor. The predominant frequency is expected to increase from "sand bar, sand dune" to "mountain", and the mean values of the peak frequency of microtremor always corresponds to this trend, except for one site classified as "sand bar, sand dune". This site is the K-NET Hamasaka station. This station has a soil profile with about 2 m fill soil on bedrock, and may



a) Sand bar, Sand dune **b) Delta (mud, clay)** **c) Alluvial fan**

d) Terrace (sand and gravel) **e) Hill** **f) Mountain**

Figure 7. The H/V ratios of microtremor for all geomorphological classification.

be stiffer than ordinary site classified by this category. And the values of peak frequencies of "alluvial fan" have wide variations and the mean value is higher than expected. Both the K-NET Kobe and Muraoka stations, mentioned above, are classified by this category. From the soil profile and the peak frequencies of the H/V spectral ratio of microtremor, both stations are stiffer than ordinary site classified by this category.

Figure 7 shows the H/V ratios of microtremor for all the geomorphological classification. The figure shows that the H/V spectrum ratios for the same geomorphological classification still exhibit wide variability. Hence, the detailed study on site response characteristics using strong motion records or microtremor is important to predict strong motion distributions although the simplified approach using only geomorphological land classification has a merit to apply to large areas.

4. CONCLUSION

Using the strong motion records obtained at seismic stations placed on the ground surface in Hyogo prefecture, Japan, site response characteristics are investigated. In order to predict the spatial distributions of strong motion indices, site amplification ratios are required in performing spatial interpolation at base rock level. Kriging technique using an attenuation relation as the trend component gave a reasonable estimate of JMA seismic intensity distribution.

Microtremor observations were carried out for all the seismic stations in Hyogo prefecture and the H/V Fourier spectral ratios of microtremor were compared with those of strong motion records. The similarity is found between the H/V ratio of microtremor and that of strong motion records, indicating both ratios are unique to the site, and hence they can be used as an index representing site amplification characteristics. A comparison between the H/V spectral ratios of microtremor and the geomorphological land classification was made, since significant variations are observed in the H/V ratios of the sites with the same geomorphological classification. Hence, the simplified site amplification evaluation using the geomorphological land classification may be limited to macroscopic prediction of strong motion distribution. On the contrary, microtremor gives good prediction of site response characteristics.

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