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EVALUATION OF S-WAVE AMPLIFICATION SPECTRUM USING MICROTREMORS

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To evaluate the site effects above the engineering base rock with an S-wave velocity of 300m/s, microtremor measurements on the ground surface were conducted in Maizuru, Japan. An estimation method of S-wave amplification spectrum using the microtremor *H/V* spectral ratio was applied at the ground surface, estimating S-wave amplification spectrum without any ground information based on the microtremor measurement results. It was found that the evaluation of S-wave amplification spectrum needs a revision on the microtremor *H/V* spectral ratio, using some coefficients on the microtopography classification and the shape of the microtremor *H/V* spectral ratio.

Keywords: S-wave amplification spectrum, Microtremor *H/V* spectral ratio, Earthquake engineering.

1 INTRODUCTION

The evaluation of site amplification effect is very important in earthquake engineering for predicting earthquake damage distribution through an accurate estimation of seismic intensity. In general, site amplification effects have been analytically evaluated by the multiple-reflection theory, using a ground-surface layer model with soil characteristics at each spot. However, it is very difficult to uniformly evaluate site amplification effects for a wider area, because there is limited and available information data, and this evaluation procedure requires a great deal of work. Therefore, site amplification effects can be evaluated from a relationship between geological features/topography obtained from simpler information and ground amplification characteristics.

An estimation method of average-ground S-wave velocity from geophysical classification (including digital national land information) and the site amplification effects using a peak velocity was proposed by Midorikawa *et al*. (1995). In recent years, a microtremor measurement has been employed to evaluate a predominant period at each spot. Nakamura (1988) reported that a spectral ratio of horizontal and vertical microtremors (hereinafter referred to as "microtremor *H/V* spectral ratio") may be artificially assumed to be a spectral amplification rate of ground surface.

It is very important to evaluate S-wave amplification spectra to mitigate earthquake damage. The evaluation of S-wave amplification spectrum needs ground information such as PS logging and boring data. However, the spots with ground information are limited. On the other hand, it is well known that the microtremor measurement method has been widely applied to the evaluation of a site effect above the engineering base rock with S-wave velocity of 300m/s. A predominant period in the microtremor *H/V* spectral ratio of ground surface corresponds to the natural period of ground surface. An estimation method of S-wave amplification spectra using the microtremor *H/V* spectral ratio at ground surface has already been proposed by Senna *et al*.(2008).

In this paper, this proposed method is applied to the east district in Maizuru city, and the S-wave amplification spectrum at the spot without any ground information is estimated based on microtremor measurement results. Both horizontal and vertical microtremors at 42 spots in Maizuru were measured by servo-type accelerometers, and the microtremor *H/V* spectral ratio and its predominant period at each spot were evaluated from microtremor accelerations.

2 OUTLINE OF MICROTREMOR MEASUREMENT

2.1 Microtremor Measurement System

Figure 1 shows a microtremor measurement system consisting of two servo-type accelerometers, a preamplifier, a data logger, a note-type PC, and a rechargeable portable battery. The sampling frequency in the microtremor measurement is 160Hz, and the measurement time is 51.2s per one set (8,192 data sets).

Figure 1. Microtremor measurement system.

2.2 Microtremor *H/V* Spectral Ratio

For this paper, the Fourier spectrum of microtremor acceleration was numerically obtained by the microtremor acceleration data of a 10s-section selected from the microtremor measurement data. The microtremor *H/V* spectral ratio can be obtained from both horizontal and vertical components of the Fourier spectrum, and that spectrum is smoothed by the Parzen window with 0.4Hz band width.

Figure 2 shows the Fourier spectra of horizontal and vertical components of measured microtremors. Microtremor *H/V* spectral ratio, defined as a ratio of horizontal components to vertical components of Fourier spectra of measured microtremor, is indicated in Figure 3. The S-wave amplification spectrum shown in Figure 3 can be analytically calculated by the multiple reflection theory, using a ground surface layer model based on the boring data. It is observed from this figure that a peak period in microtremor *H/V* spectral ratio almost accords with a peak period in the S-wave amplification spectrum. Consequently, this implies that the predominant period at the spot without any boring data or ground information can be easily and accurately evaluated from the microtremor *H/V* spectral ratio.

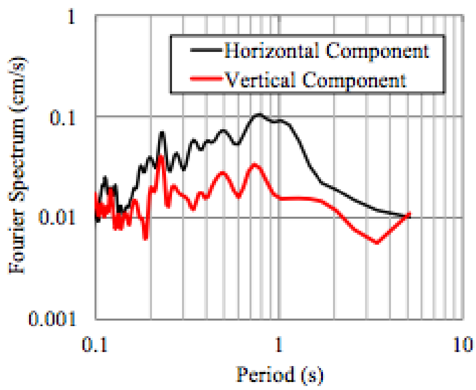


Figure 2. Fourier spectra of microtremor accelerations.

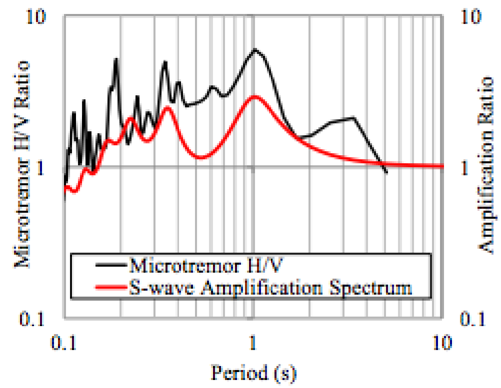


Figure 3. Microtremor *H/V* spectral ratio and S-wave amplification spectrum.

3 ESTIMATION METHOD OF S-WAVE AMPLIFICATION SPECTRUM

Senna *et al.* (2008) investigated a relationship between the amplification spectrum and the microtremor *H/V* spectral ratio based on ground characteristics at K-NET and KiK-net acceleration observation spots in Japan, and also proposed a simple estimation method to obtain the amplification spectrum from the microtremor *H/V* spectral ratio. S-wave amplification spectrum is estimated by this estimation method in this paper. This estimation method is briefly described below.

S-wave amplification spectrum, based on the engineering base rock with an S-wave velocity of 300m/s, can be evaluated from the microtremor *H/V* spectral ratio by making corrections in some coefficients concerned with the microtopography classification, and with the shape of microtremor *H/V* spectrum ratio at each spot. The S-wave amplification spectrum $G(T)$ can be given by the following equation:

$$G(T) = \frac{HV_j(T)}{\alpha_k \cdot \beta'_m(T)} \tag{1}$$

where α_k is a correlation rate on the microtopography classification k at spot j, $HV_j(T)$ is a microtremor H/V spectrum ratio at the microtopography classification k at spot j, and $\beta'_m(T)$ is a correction rate transformed by a correction rate $\beta'_m(T/T_0)$ from a peak period $T_0$to T. $\beta'_m(T/T_0)$ is a correction rate in the microtopography classification *m* at spot j. Microtremor H/V spectral ratio is classified into three groups of Group A (mountain and hilly district), Group B (tableland) and Group C (low-lying area). $\beta'_m(T/T_0)$ can be obtained from the following equations using both the cosine-type function and the given coefficients *a* ~ *h*.

$$\left.\begin{array}{ll}
\beta'_m(T/T_0) = a + b\cdot\cos(3.33\pi\cdot(T/T_0) - 1.0) & (0.1 < T/T_0 < 0.4)\\
\beta'_m(T/T_0) = c + d\cdot\cos(1.67\pi\cdot(T/T_0) + 0.95) & (0.4 < T/T_0 < 1.0)\\
\beta'_m(T/T_0) = e + f\cdot\cos(2\pi\cdot(T/T_0) + 6.0) & (1.0 < T/T_0 < 1.5)\\
\beta'_m(T/T_0) = g + h\cdot\cos(\pi\cdot(T/T_0) + \pi) & (1.5 < T/T_0 < 2.0)\\
\beta'_m(T/T_0) = 1.0 & (2.0 < T/T_0, 0.1 > T/T_0)
\end{array}\right\} \quad (2)$$

4 S-WAVE AMPLIFICATION SPECTRUM RESULTS

The S-wave amplification spectrum at the measuring spot is evaluated as above.

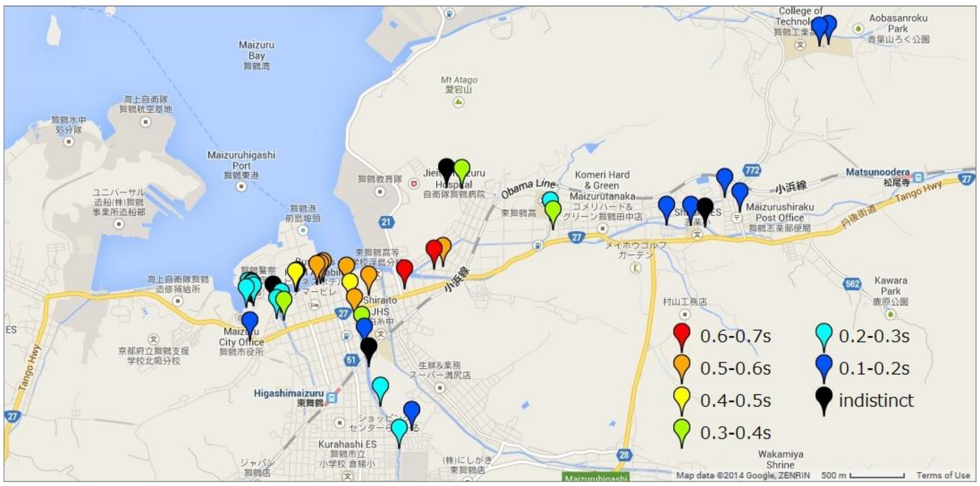


Figure 4. Predominant period distribution in microtremor *H/V* ratio (NS component).

Figure 5. Predominant period distribution in microtremor *H/V* ratio (EW component).

Figures 4 and 5 show the predominant period distributions of microtremor *H/V* spectral ratio in both NS and EW components at 42 spots in Maizuru, respectively. The word "indistinct" in these figures means that there seems to be no distinct peak in a microtremor *H/V* spectral ratio. There are several spots whose NS component is longer than the EW component. The seaside area of Maizuru has a soft and thick sedimentary stratum with a long predominant period between 0.5s and 0.6s. Sakai (2005) reported that structures at the ground with a predominant period of about 0.6s, have a high correlation relationship with structure damage during severe earthquakes, and tend to be damaged by a strong earthquake motion. Accordingly, it is possible that structure damage in Maizuru seaside will be larger during a severe earthquake ground motion.

Figure 5 indicates a comparison of the theoretical amplification spectrum (under the multiple reflection theory) with the microtremor *H/V* spectral ratios at both Hama dormitory and Hama district with ground boring data. NS and EW components of the amplification spectrum obtained by Senna's method are also illustrated in Figure 5. S-wave velocity V_s can be calculated by the following empirical equation (Ohta 1978):

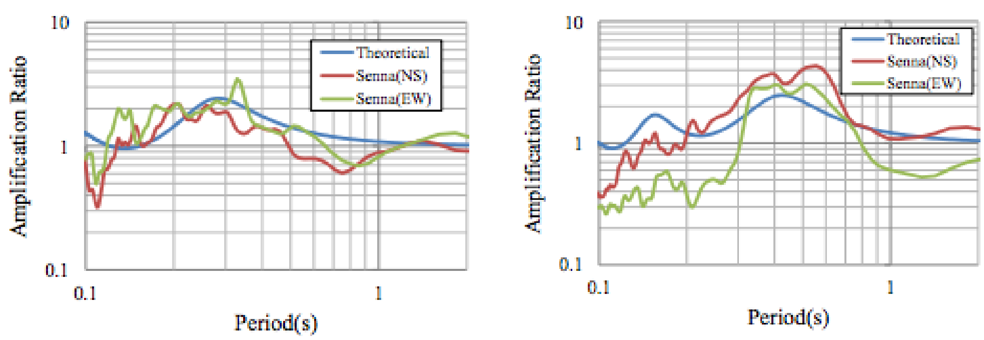
$$V_S = 62.48 N^{0.218} \cdot H^{0.228} \cdot F \tag{3}$$

where N is N-value in the standard penetration test, H is depth, and F is a coefficient on soil classification, i.e., 1.073 for sand, 1.0 for clay, and 1.199 for gravel. S-wave velocity of the engineering base rock is assumed to 300m/s. The density ρ can be obtained by the following equation proposed by Kobayashi *et al*. (1995):

$$\rho = 0.67\sqrt{V_S / 1000} + 1.4 \tag{4}$$

The damping coefficient h in the evaluation process of theoretical value of S-wave amplification spectrum is given by the following equation:

$$h = 7.5 / V_s \tag{5}$$



(a) Hama Dormitory.

(b) Hama District.

Figure 6. Comparison of amplification spectrums in theoretical value and Senna's method.

As can be seen in Figure 6, although the amplification ratio of the S-wave amplification spectrum is out of accord with that obtained by the multiple reflection theory, the peak period of S-wave amplification spectrum relatively corresponds to that evaluated by the simple estimation method employed in this paper. Also, the S-wave amplification spectrum evaluated from the microtremor *H/V* spectral ratio tends to underestimate that obtained by the multiple reflection theory. However, S-wave amplification spectrum evaluated from the microtremor *H/V* spectral ratio seems to underestimate or overestimate if a misjudgment on a correlation rate α_k occurs in the microtopography classification. This is because the microtopography classification mesh for the geological stratum distribution does not correspond accurately to the detailed change of real ground stratum. Consequently, the simple estimation method using microtremor *H/V* spectral ratio used in this paper has a sufficient accuracy in the evaluation of S-wave amplification spectrum.

5 CONCLUSIONS

In this paper, horizontal and vertical microtremor observations at 42 spots in Maizuru city were conducted by servo-type accelerometers, and the microtremor *H/V* spectral ratio and its predominant period at each spot were evaluated from microtremor accelerations. The S-wave amplification spectrum at the spot without any ground information was evaluated based on microtremor measurement results. The theoretical amplification spectrum evaluated from the multiple reflection theory was compared with the microtremor *H/V* spectral ratios at two spots with ground boring data. The summary obtained in this paper is as follows:

(1) The S-wave amplification spectrum can be easily evaluated from the microtremor *H/V* spectral ratio.
(2) An evaluation of S-wave amplification spectrum needs a revision of the microtremor *H/V* spectral ratio using some coefficients on the microtopography classification and the shape of the microtremor *H/V* spectral ratio.
(3) Both the microtremor *H/V* spectral ratio and S-wave amplification spectrum in the seaside area in Maizuru city trend to have a long predominant period, where extensive damage to structures may occur during a strong earthquake.
(4) Further investigation on the microtremor *H/V* spectral ratio may be needed to accurately evaluate S-wave amplification spectrum and make concrete conclusions.

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