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Seismic damage prediction of wooden house using predominant period of ground

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ABSTRACT

The evaluation of a site amplification effect is very important in earthquake engineering when a seismic damage to wooden house with a low seismic performance will be predicted by an accurate estimation of the seismic intensity at surface ground. In this paper, both horizontal and vertical microtremors at 75 measuring sites in the east district in Maizuru city were measured by servo type accelerometers, and also the predominant periods at 353 sites in the same area were numerically estimated from the predominant periods measured at 75 sites using the Inverse Distance Weighting method. Moreover, a seismic damage prediction of wooden house against a strong earthquake ground motion was conducted by a relationship between a seismic damage function and a maximum drift angle of wooden house. A collapse ratio of wooden house due to the predominant period of surface ground layer can be evaluated from the seismic damage functions with a base shear coefficient.

1. INTRODUCTION

The evaluation of a site amplification effect, that is, a predominant period of surface ground is very important in the earthquake engineering when a seismic damage distribution of wooden house will be predicted by an accurate estimation of the seismic intensity. In general, the site amplification effect has been analytically evaluated by the multiple reflection theory using a surface ground layer model with the soil characteristics at each observation site. However, it is so difficult to uniformly and accurately evaluate site amplification effect for a wider area, because there is a limited and available information data and this evaluation procedure needs a great amount of work. Therefore, site amplification effects can be evaluated from a relationship between the geolog-

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ical features/topography obtained from much simpler information and ground amplification characteristics.

An estimation method of not only the average ground S-wave velocity from geophysical classification including the digital national land information but also the site amplification effects using a peak velocity was proposed by Midorikawa *et al*. (1995). In recent years, a microtremor measurement has been easily employed in order to evaluate a predominant period at each observation site. Nakamura *et al*. (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 surface ground.

It is very important in the earthquake disaster prevention to accurately evaluate the predominant period at surface ground. The evaluation of predominant period needs the ground information of such as PS logging and boring data. However, the observation sites 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 procedure of a site amplification 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 surface ground. An estimation method of S-wave amplification spectrum using the microtremor *H/V* spectral ratio at surface ground has already proposed by Senna *et al*. (2008).

Using the geomorphological land classification method proposed by Senna *et al*. (2008), S-wave amplification spectrum at the observation site without any ground information was evaluated based on the microtremor measurement results (Nishikawa and Takatani, 2014a, 2014b). Both horizontal and vertical microtremors at 75 sites in the east district in Maizuru city were measured by servo type accelerometers, and the microtremor *H/V* spectral ratio and its predominant period at each observation site were evaluated from microtremor accelerations (Nishikawa and Takatani, 2014c). Also, the predominant periods at unmeasured 353 sites are numerically evaluated from the measured 75 sites by the Inverse Distance Weighting method proposed by Shepard (1968).

Tokimatsu *et al*. (2007) reported that a seismic damage to wooden structure is greatly related to a predominant period of surface ground in the 2004 Mid Niigata Prefecture Earthquake and the 2007 Noto Peninsula Earthquake. In general, there is a certain relationship between a predominant period of surface ground and a seismic damage to wooden house in past earthquakes in Japan. Seismic damage to wooden house can be reduced against a strong earthquake ground motion through making an evaluation of seismic damage to wooden house due to a predominant period of ground.

In this paper, a collapse ratio of wooden house in the east district in Maizuru city is evaluated from a predominant period distribution of the surface ground in this area. The collapse ratio of wooden house can be evaluated by a seismic damage function using a predominant period distribution of surface ground as a parameter. A seismic damage function is needed an estimation of a collapse ratio of wooden house at a certain surface ground observation site against an assumed strong earthquake motion. In general, there may be a significant relationship between a maximum drift angle and a seismic damage to wooden structure. Based on the analytical results of a maximum drift angle of wooden structure against an assumed strong earthquake motion, a collapse ratio for a base shear coefficient of wooden house is analytically evaluated in this paper.

2 OUTLINE OF MICROTREMOR MEASUREMENT

2.1 Microtremor Measurement System

Photo 1 shows a microtremor measurement system, which consists of a preamplifier, a data logger, two servo-type accelerometers, a rechargeable portable battery, and a PC. Sampling frequency of a microtremor measurement is 160Hz, and its measurement time is 51.2s per one set (8,192 data number). Table 1 shows an outline of the microtremor measurement instruments shown in Photo 1 which were used in the microtremor *H/V* spectral ratio measurement at 75 measuring sites in the east district in Maizuru city.

2.2 Microtremor H/V Spectral Ratio

In this paper, Fourier spectrum of a microtremor acceleration is numerically obtained

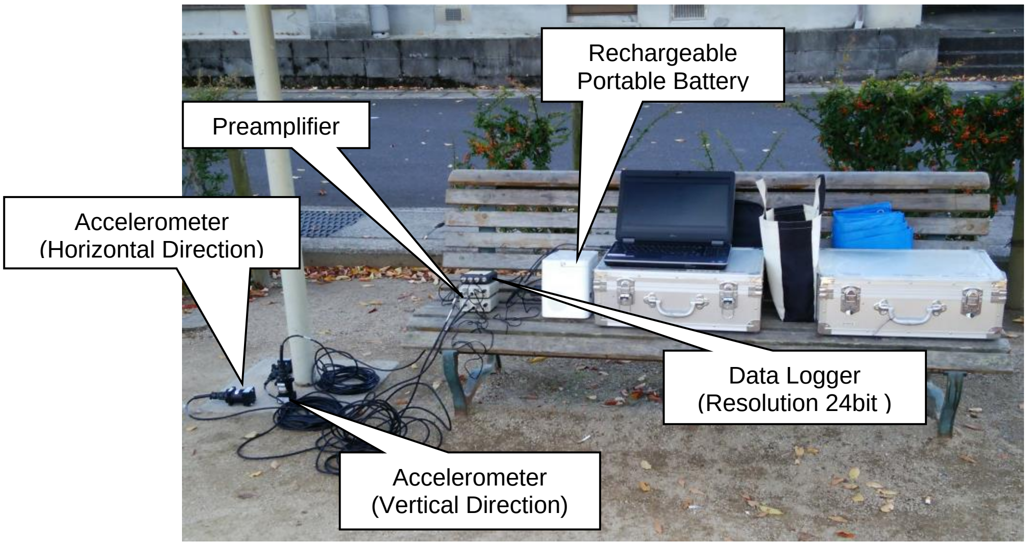


Photo 1. Microtremor measurement system

Table 1. Outline of instruments used in microtremor measurement

Instrument Name	Outline
Real Time Vibration Analysis Device (DSA-PHOTON)	Frequency Range : Maximum 21,000Hz A/D Transformation : 24-bit resolution D/A Transformation : 24-bit resolution
Real Time Vibration Wave Controlling System (DSA-RTPro)	Vibration Output Function, FFT Analysis Function, Long Term Vibration Recording Function, Measurement Data Editing Function
Servo-type Accelerometer (V405-BR)	Measurement Range : +-30m/s^2, Resolution 1x10^{-6} m/s^2
Preamplifier (PA-9102)	Frequency Range : 0.3 – 45 Hz

from the microtremor acceleration data of 10s section selected from microtremor measurement data. Microtremor *H/V* spectral ratio can be obtained from both horizontal and vertical components of Fourier spectrum of microtremor acceleration, and then Fourier spectrum of microtremor can be smoothed by Parzen window with 0.4Hz band width. The microtremor *H/V* spectral ratio used in this paper is given by the following equation.

$$\frac{H}{V}=\sqrt{\left(\frac{H}{V}\right)^2_{NS-UD}+\left(\frac{H}{V}\right)^2_{EW-UD}} \tag{1}$$

where, H/V is an average spectral ratio, $(H/V)_{NS-UD}$ and $(H/V)_{EW-UD}$ are NS and EW components of spectral ratio, respectively.

Figure 1 shows Fourier spectra of both horizontal and vertical components of measured microtremors. Microtremor *H/V* spectral ratio, which is defined by a ratio of horizontal component to vertical one of Fourier spectra of measured microtremor, is indicated in Figure 2. S-wave amplification spectrum shown in Figure 2 can be analytically

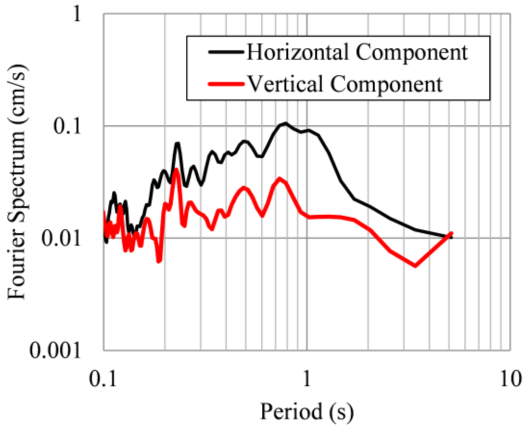


Figure 1. Fourier spectra of microtremor ratio accelerations wave spectrum

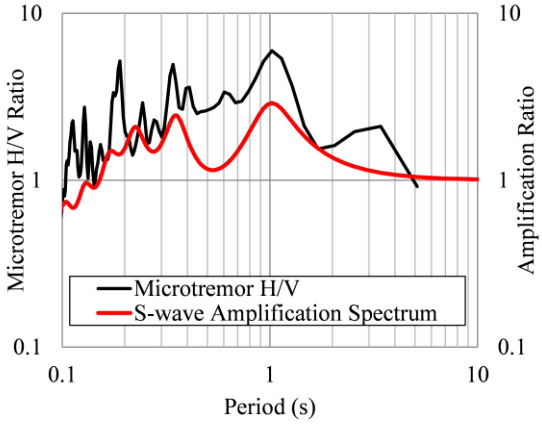
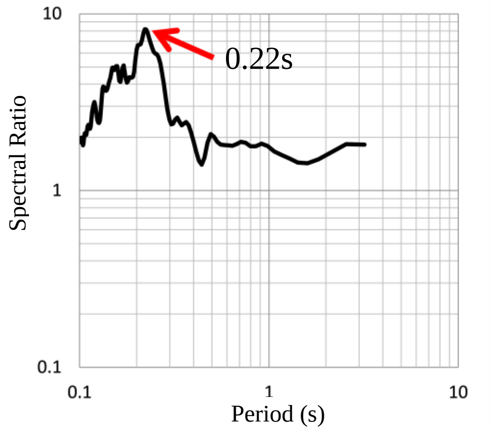
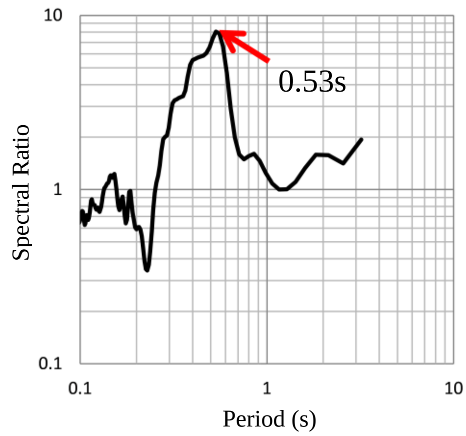


Figure 2. Microtremor *H/V* spectral and S-wave amplification



(a) A site



(b) B site

Figure 3. Microtremor *H/V* spectral ratio

calculated by the multiple reflection theory using a surface ground layer model based on a ground boring data. It is found from Figure 3 that some peak frequencies of H/V spectral ratio have a good agreement with those of S-wave amplification spectrum.

Figure 3 shows the microtremor *H/V* spectral ratios at A and B sites shown in Figure 4 described later. Microtremor *H/V* spectral ratio is defined by a ratio of horizontal component to vertical one of Fourier spectra of measured microtremor. It is found that a peak period in microtremor *H/V* spectral ratio shown in Figure 3 almost accords with a peak period in S-wave amplification spectrum. Consequently, this implies that the predominant period at the site without any boring data or ground information can be easily and accurately evaluated from the microtremor *H/V* spectral ratio.

3 ESTIMATION OF H/V SPECTRSL RATIO BY THE INVERSE DISTANCE WEIGHTING METHOD

In this paper, a microtremor *H/V* spectral ratio at unmeasured site can be numerically estimated by the following Inverse Distance Weighting method (Shepard, 1968).

$$H/V = \sum_{i=1}^{N} w_i (H/V)_i \qquad (2)$$

$$w_i = \frac{1/r_i^2}{\sum_{i=1}^{N} 1/r_i^2} \qquad (3)$$

where, $(H/V)_i$ is a microtremor *H/V* spectral ratio at i-th site, w_i is a weight at *i*-th measuring site, r_i is a distance between i-th measuring site and unmeasured one, and N is a total number of measured sites.

Figure 4 shows the microtremor *H/V* spectral ratios at 75 measured sites, and Figure 5 indicates a microtremor *H/V* spectral ratio distribution map estimated by the Inverse Distance Weighting method described above. Microtremor *H/V* spectral ratios at 335 estimating sites were numerically obtained from the *H/V* spectral ratios at 75 measured sites shown in Figure 4. It should be noted that *H/V* spectral ratio at the estimating site can be obtained by these equations (2) and (3) under the limited microtremor observations of 75 sites. It is found from Figure 5 that the microtremor *H/V* spectral ratio in the seaside area in the east district in Maizuru city trends to have a long predominant period, where an extensive damage to the old wooden structure with a low seismic performance may occur during a strong earthquake ground motion.

Figure 6 illustrates an old map of the east district in Maizuru city in 1901. Red line in this figure means a present road location in this area. The roads in seaside area surrounded in thick blue line are located in a sea area and also a mouth of the Yohoro river is located on the Gojoh street at the present map. It is found that the seaside area and the Yohoro river area surrounded in thick red line have a long predominant period because of a soft and weak soil ground. Sakai (2005) reported that a structure on the surface ground with a predominant period of about 0.6s, where has a high correlation relationship with structure damage against a strong earthquake, trends to be damaged by a strong earthquake motion. Accordingly, there may be a high possibility that the structure damage in the seaside area of the east district in Maizuru city will be much

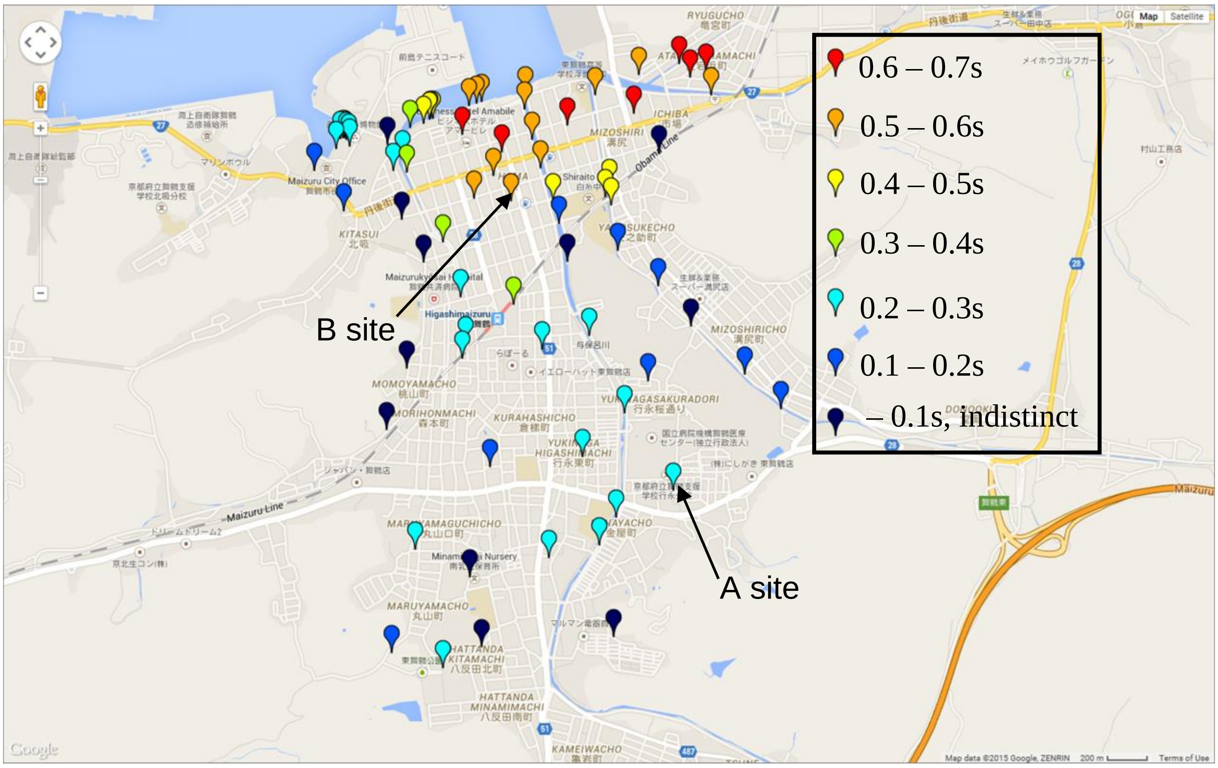


Figure 4. Microtremor measurement sites in the east district in Maizuru city

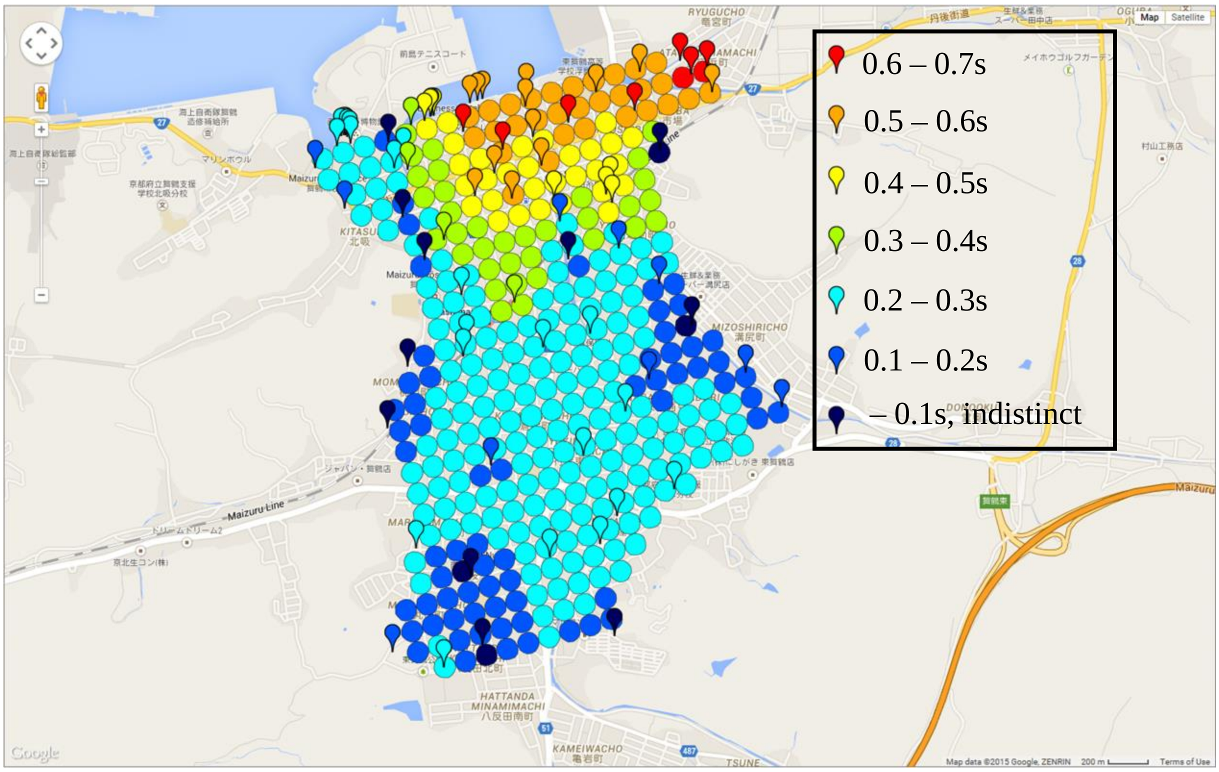


Figure 5. Evaluation of predominant period distribution using microtremor *H/V* spectral ratio

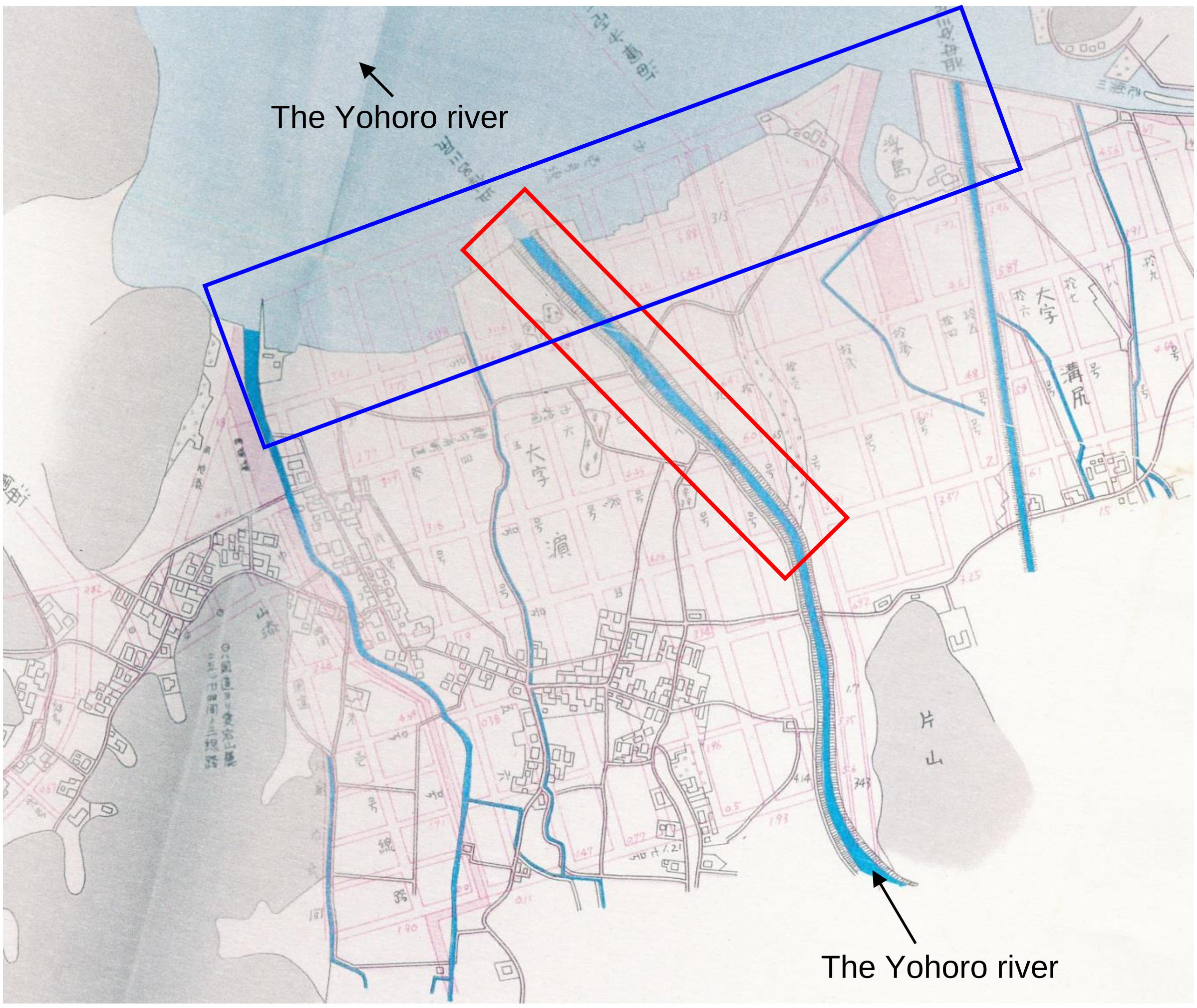


Figure 6. Old map of the east district in Maizuru city (1901)

larger than other area against a strong earthquake ground motion. In particular, many old wooden houses with a low seismic performance in this area will suffer a large seismic damage or have a dangerousness of collapsing against a strong earthquake ground motion.

4 SEISMIC DAMAGE ESTIMATION OF WOODEN HOUSE WITH LOW SEISMIC PERFORMANCE

In general, there is a certain significant relationship between a predominant period of the surface ground layer and a seismic damage to wooden house in past earthquakes in Japan. In addition, a base shear coefficient Cy of wooden structure may be greatly related with the seismic damage against a strong earthquake ground motion. Based on the seismic damage function for a base shear coefficient Cy, the seismic damage estimation of wooden house with a low seismic performance is conducted using a predominant period of surface ground evaluated in the previous section.

4.1 Seismic Damage Function

In this paper, a collapse ratio of wooden house in the east district in Maizuru city is estimated from a predominant period distribution of the surface ground in this area. The collapse ratio of wooden house can be estimated by a seismic damage function using a predominant period distribution of surface ground as a parameter. A seismic damage function is needed an estimation of the collapse ratio of wooden house at a certain surface ground site against an assumed strong earthquake motion. In general, there may be a significant relationship between a maximum drift angle and a seismic damage to wooden structure against a strong earthquake. In this paper, a collapse ratio of wooden house is analytically estimated using the analytical results of a maximum drift angle of wooden structure against an assumed strong earthquake motion.

Figure 7 indicates a relationship between a base shear coefficient Cy and a drift angle R. Several signs of M_e, H_e, Q, R, R_y, and $M_e g C_y$ in Figure7 mean an effective

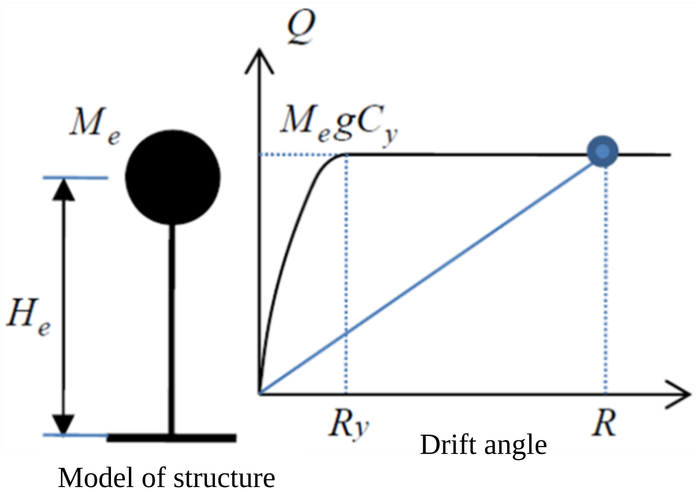


Figure 7. Relationship between a base shear coefficient and a drift angle

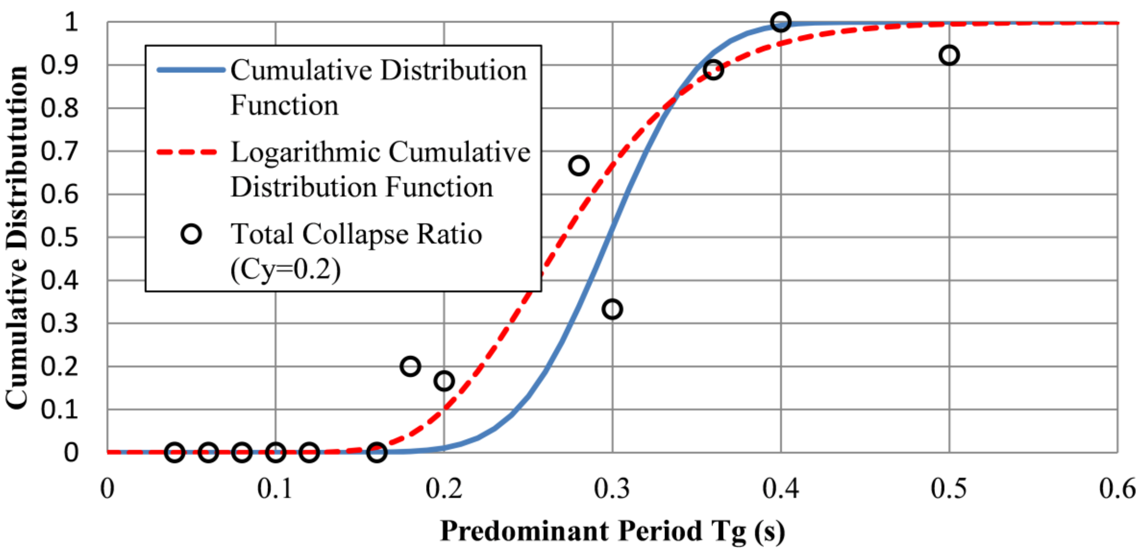


Figure 8. Seismic damage function of wooden house (Cy=0.2)

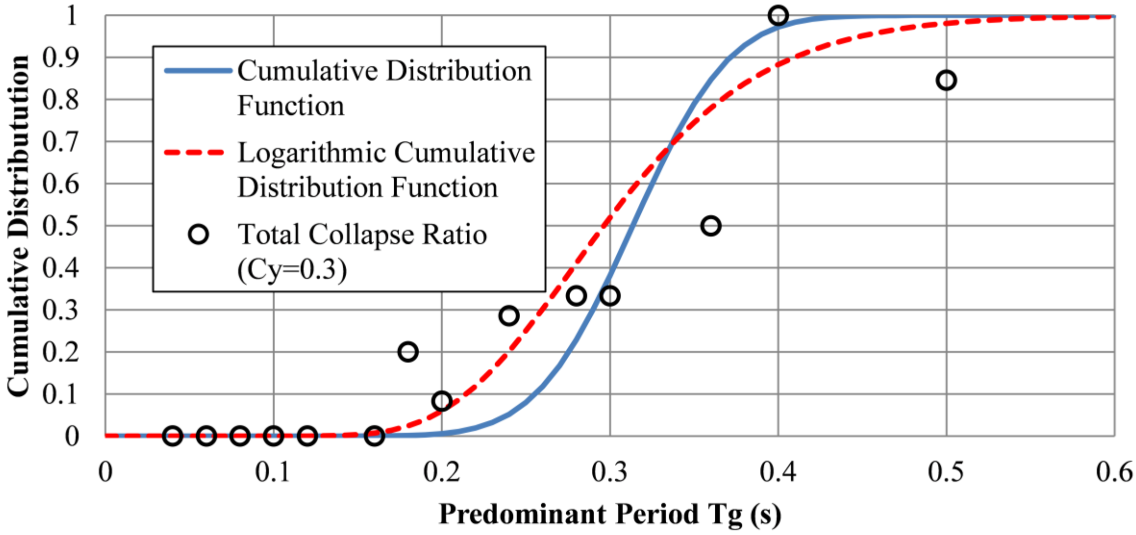


Figure 9. Seismic damage function of wooden house (Cy=0.3)

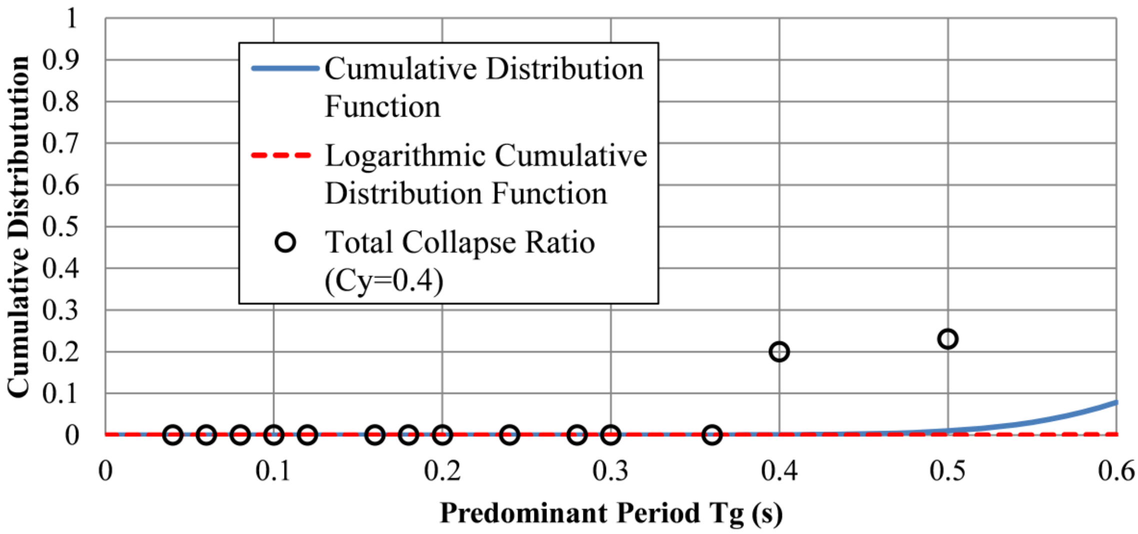


Figure 10. Seismic damage function of wooden house (Cy=0.4)

mass and an effective height of structure, a horizontal load, a drift angle, a maximum drift angle, and a yielding load, respectively. It is found from Figure 7 that a seismic performance of structure is higher with increase of the base shear coefficient Cy. Seismic damage function is evaluated for three base shear coefficients Cy=0.2, 0.3, and 0.4 in this paper.

The maximum drift angle of a two-story wooden structure is analytically calculated using a simulated earthquake ground motion wave due to a ground boring data in this paper. Based on a calculation result for each predominant period of surface ground, a collapse ratio of wooden structure in this paper is defined as a percentage that the maximum drift angle is over 1/30.

A seismic damage function for each base shear coefficient Cy of wooden structure can be obtained from a curve fitting technique, which a cumulative distribution function given by a logarithmic normal distribution is applied to the relationship between the predominant period of surface ground and the collapse ratio of wooden structure. Seismic damage to wooden house in the east district in Maizuru city can be numerically evaluated using the seismic damage function of wooden structure obtained from the procedure previously mentioned.

Figures 8, 9 and 10 show seismic damage functions for three base shear coefficients Cy=0.2, 0.3, and 0.4, respectively. Using these seismic damage functions, seismic damage for each base shear coefficient Cy of wooden house can be numerically evaluated against an assumed strong earthquake motion.

4.2 Evaluation of Collapse Ratio of Wooden House

In this section, based on a predominant period distribution evaluated from the microtremor *H/V* spectral ratios shown in Figure 5, collapse ratio of wooden house in the east district in Maizuru city is numerically evaluated from the seismic damage function for a base shear coefficient Cy of wooden house.

Figures 11, 12 and 13 illustrate each collapse ratio distribution of wooden house for three base shear coefficients Cy=0.2, 0.3 and 0.4, respectively. In this paper, a strong earthquake ground motion with the Japan Meteorological Agency(JMA) seismic intensity of "6 upper" level is assumed. It is found from the collapse ratio distribution in the base shear coefficients Cy=0.2, 0.3 shown in Figures 11 and 12 that the collapsing percentage of seismic damage to wooden house with a low seismic perfor-

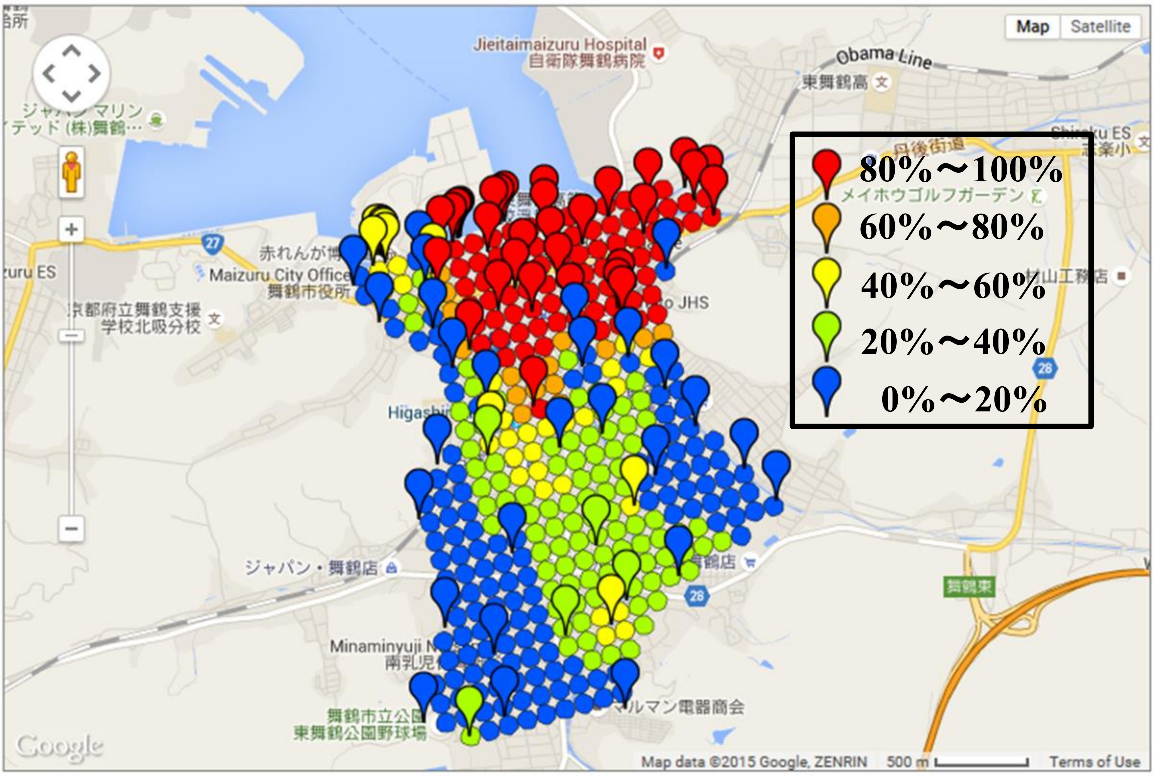


Figure 11. Collapse ratio of wooden house (Cy=0.2)

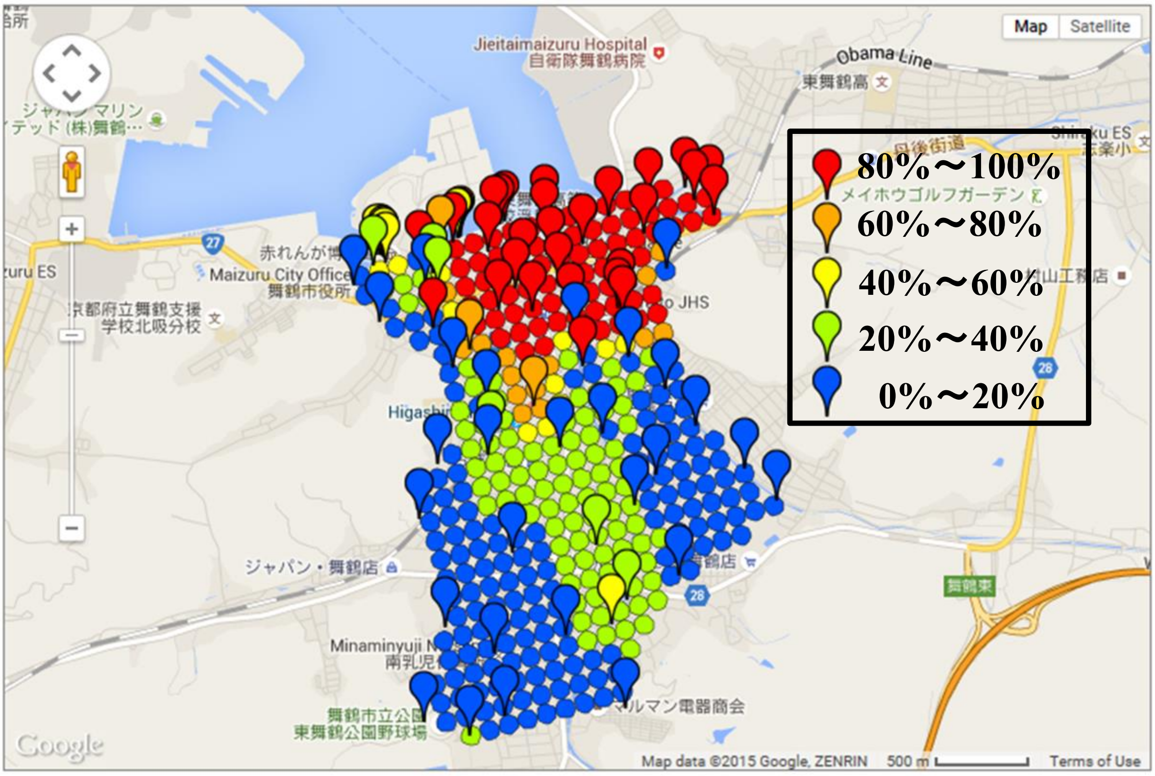


Figure 12. Collapse ratio of wooden house (Cy=0.3)

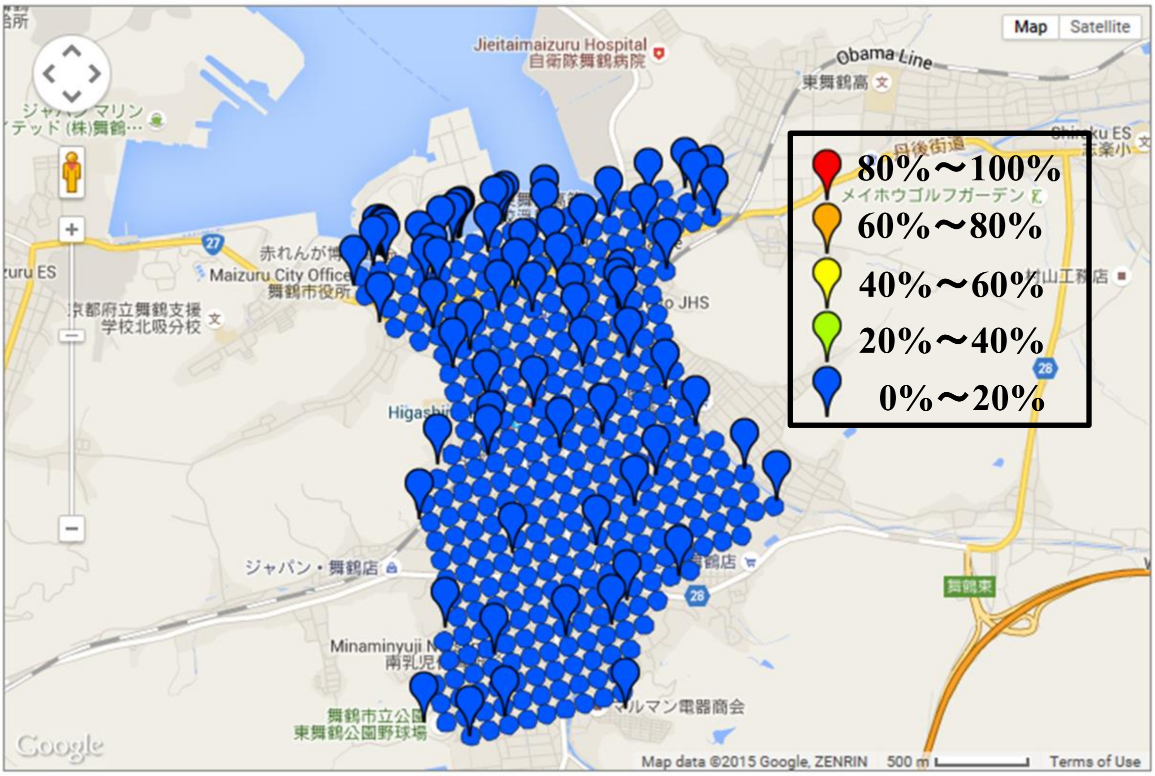


Figure 13. Collapse ratio of wooden house (Cy=0.4)

mance in the area whose predominant period is more than 0.4s is higher than other area. On the other hand, the collapse ratio distribution in the base shear coefficient Cy=0.4 shown in Figure 13 is much lower than those in the base shear coefficients Cy=0.2 and 0.3. This is because the wooden house with a high seismic performance does not collapse against a strong earthquake motion with the JMA seismic intensity of “6 upper” level.

5 CONCLUSIONS

In this paper, both horizontal and vertical microtremors at 75 sites in the east district in Maizuru city were measured by servo type accelerometers, and the microtremor *H/V* spectral ratio and its predominant period at each measuring site were evaluated from microtremor accelerations. Also, the predominant periods at 353 unmeasured sites were numerically evaluated from 75 measured sites by the Inverse Distance Weighting method. Moreover, a collapse ratio of wooden house in the east district in Maizuru city was numerically evaluated from the seismic damage function for a base shear coefficient Cy of wooden house, based on a predominant period obtained from the microtremor *H/V* spectral ratios. A collapse ratio of wooden house was analytically estimated using the analytical results of a maximum drift angle of wooden structure against an assumed strong earthquake motion with the JMA seismic intensity of “6 upper” level.

The summary obtained in this paper is as follows.

(1) S-wave amplification spectrum at even the site without any ground information can be easily and quickly evaluated from the microtremor *H/V* spectral ratio obtained from a microtremor measurement system using servo-type accelerometers.
(2) Both the microtremor *H/V* spectral ratio and S-wave amplification spectrum in the seaside area in the east district in Maizuru city trend to have a long predominant period. Therefore, there may be a high possibility that the structure damage in the seaside area of the east district in Maizuru city will be much larger than other area against a strong earthquake ground motion.
(3) The seismic damage function of wooden structure can be obtained from a curve fitting technique, by which a cumulative distribution function given by a logarithmic normal distribution is applied to the relationship between the predominant period of surface ground and the collapse ratio of wooden structure.
(4) The seismic damage to wooden house in the east district in Maizuru city can be numerically evaluated using the seismic damage function of wooden structure.
(5) Collapsing percentage of seismic damage to wooden house with a low seismic performance in the area whose predominant period is more than 0.4s is higher than other area.

The challenge of the future is to make an accurate evaluation of S-wave amplification spectrum by using the microtremor *H/V* spectral ratio map in Maizuru city. In addition to the evaluation of a predominant period of the surface ground layer, it is very important to accurately evaluate a seismic damage function for a base shear coefficient Cy of wooden structure based on the relationship between a maximum drift angle and a predominant period of surface ground layer above the engineering base rock. In particular, seismic damage prediction of wooden structure greatly depends on the seismic damage function of a base shear coefficient Cy. Therefore, further investigation on the seismic damage prediction of old wooden structure with a low seismic performance may be needed to accurately evaluate the seismic damage function of wooden structure and make some concrete conclusions.

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