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SEISMIC DAMAGE PREDICTION OF OLD JAPANESE-STYLE WOODEN HOUSE USING PREDOMINANT PERIOD DISTRIBUTION OF GROUND SURFACE LAYER

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In general, 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 against a strong earthquake will be predicted by an accurate estimation of the seismic intensity at surface ground. In this paper, both horizontal and vertical microtremors at 51 measuring sites in the west district in Maizuru city were measured by servo type accelerometers, and also the predominant periods at 727 sites in the same area were numerically estimated from the predominant periods measured at 51 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.

Keywords: Microtremor observation, Vulnerability function, Maximum drift angle of wooden house, Inverse distance weighting method.

1 INTRODUCTION

The evaluation of a site amplification effect, that is, a predominant period of surface ground layer plays a very important key role in the earthquake engineering when a seismic damage distribution of wooden house with low seismic performance 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 the 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, some site amplification effects can be evaluated from a relationship between the geological features/topography obtained from much simpler information and ground amplification characteristics. S-wave amplification spectrum at the observation site without any ground information was evaluated based on the microtremor measurements (Nishikawa and Takatani 2014).

In this paper, both horizontal and vertical microtremors at 51 sites in the west district in Maizuru city were measured by servo type accelerometers, and also the predominant periods at 727 sites in the same area were numerically evaluated from the predominant periods measured at

51 sites. Moreover, seismic damage prediction of wooden house against a strong earthquake ground motion with the Japan Meteorological Agency seismic intensity of "5 lower to 6 upper" level was conducted by the relationship between the vulnerability function and the maximum drift angle of wooden house.

2 OUTLINE OF MICROTREMOR MEASUREMENT

2.1 Microtremor Measurement System

Figure 1 shows a microtremor measurement system, which consists of a preamplifier, a data logger, three 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 51 measuring sites in the east district in Maizuru city.

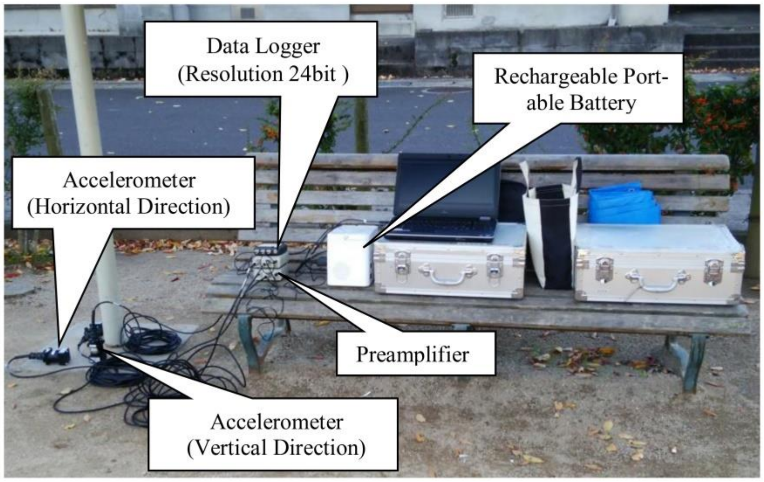


Figure 1. Microtremor measurement system.

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 : $\pm 30 \text{m/s}^2$, Resolution 1×10^{-6} m/s^2
Preamplifier (PA-9102)	Frequency Range : 0.3 – 45 Hz

2.2 Microtremor H/V Spectral Ratio

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

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

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.

3 ESTIMATION OF H/V SPECTRAL 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).

$$H/V = \sum_{i=1}^{N} w_i (H/V)_i \ , \ w_i = \frac{1/r_i^2}{\sum_{i=1}^{N} 1/r_i^2} \tag{2}$$

where, $(H/V)_i$ is a microtremor H/V spectral ratio at ***i***-th site, 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 2 shows the microtremor H/V spectral ratios at 51 measured sites, and Figure 3 indicates a microtremor H/V spectral ratio distribution map estimated by the Inverse Distance Weighting method described above. Microtremor H/V spectral ratios at 727 estimating sites were numerically obtained from the H/V spectral ratios at 51measured sites shown in Figure 3. It should be noted that H/V spectral ratio at the estimating site can be obtained by Equation (2)

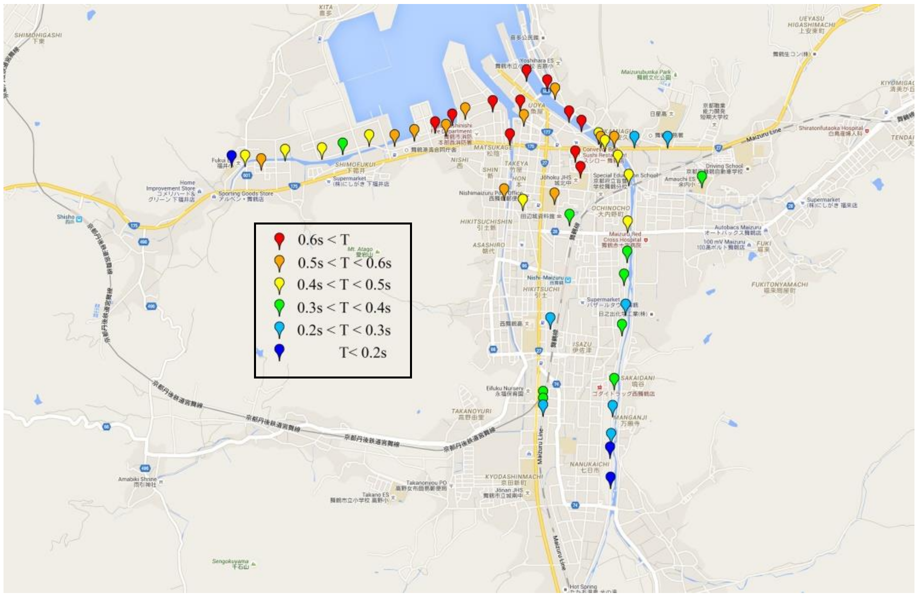


Figure 2. Microtremor measuring points in the west district in Maizuru city.

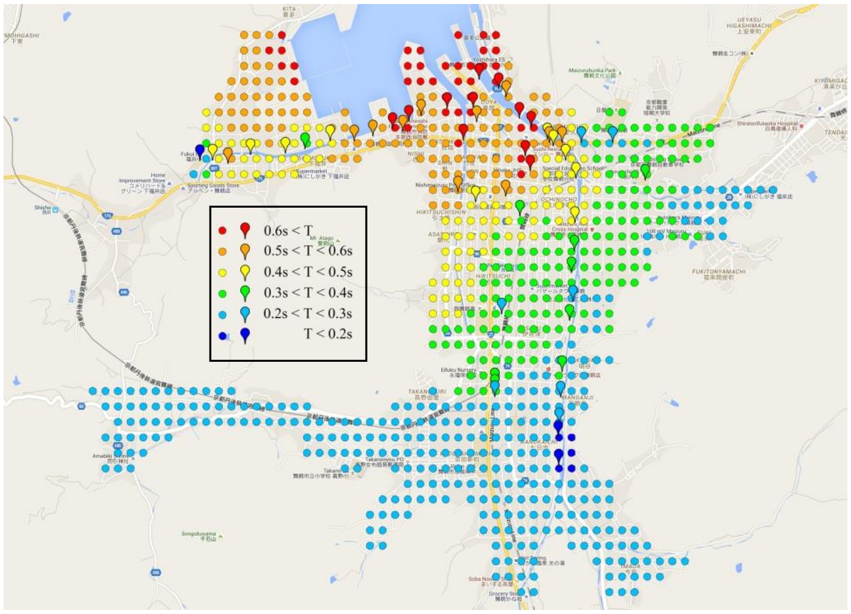


Figure 3. Predominant period interpolation result by microtremor measuring points.

under the limited microtremor observations of 51 sites. It is found from Figure 3 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.

4 SEISMIC DAMAGE ESTIMATION OF WOODEN HOUSE WITH LOW SEISMIC PERFORMANCE

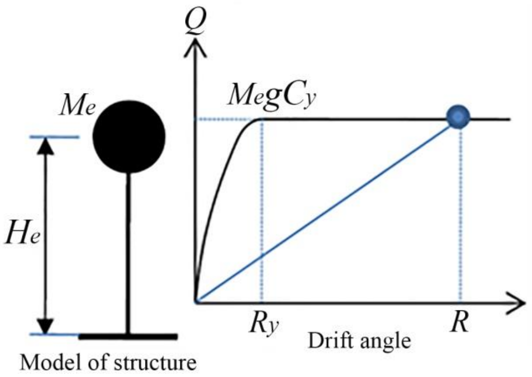
4.1 Seismic Damage Function

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 earth-quakes in Japan. In addition, a base shear coefficient C_y 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 C_y, 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.

Figure 4 indicates a relationship between a base shear coefficient C_y and a drift angle R. Several signs of M_e, H_e, Q, R, R_y, and $M_e g C_y$ in Figure 4 mean an effective 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 4 that a seismic performance of structure is higher with increase of the base shear coefficient C_y. Seismic damage function is evaluated for three base shear coefficients $C_y = 0.2$, 0.3, and 0.4 in this paper.

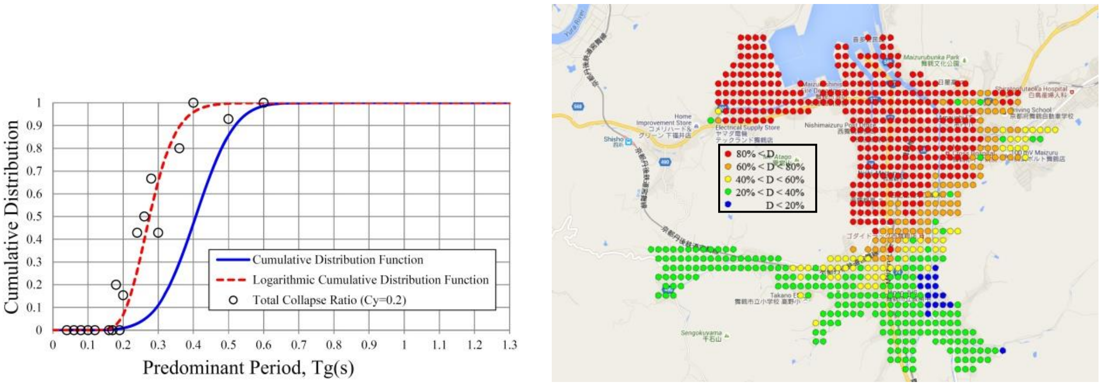
The maximum drift angle of a two-story wooden structure is analytically calculated using a simulated earthquake ground motion wave due to a ground boring data in this paper. Based on a calculation result for each predominant period of surface ground, a total collapse ratio of wooden structure in this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

A seismic damage function for each base shear coefficient C_y 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 total 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.



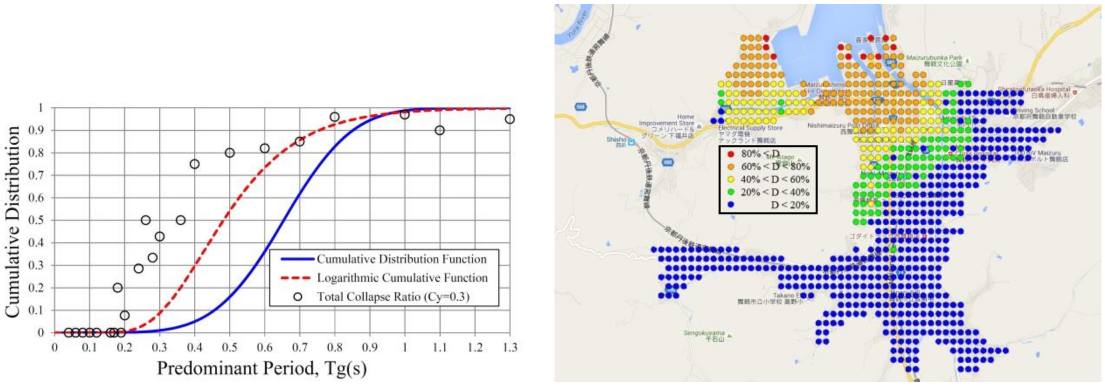
Q: Horizontal load
R: Drift angle
C_y: Base shear coefficient
H_e: Effective height
M_e: Effective mass
R_y: Drift angle at yielding point
g: Gravity acceleration

Figure 4. Relationship between a base shear coefficient and a drift angle.



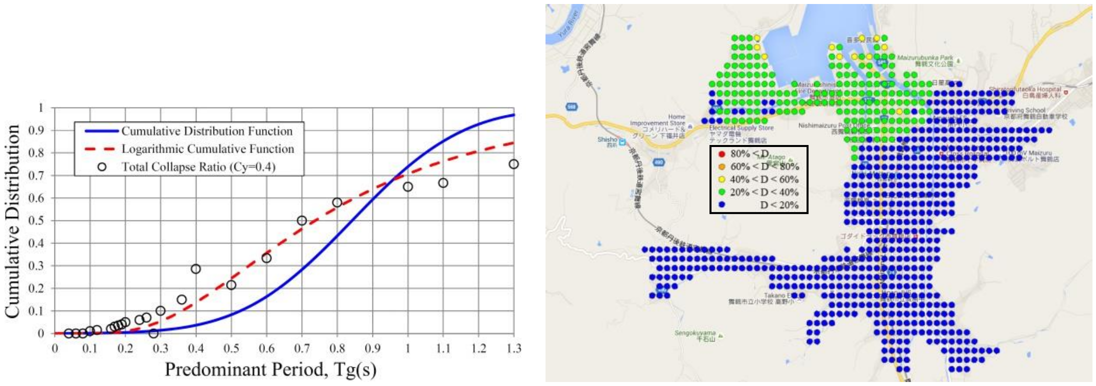
(a) Collapsing ratio vs. predominant period (b) Interpolation result

Figure 5. Relationship between a base shear coefficient C_y=0.2 and a drift angle.



(a) Collapsing ratio vs. predominant period (b) Interpolation result

Figure 6. Relationship between a base shear coefficient C_y=0.3 and a drift angle.



(a) Collapsing ratio vs. predominant period (b) Interpolation result

Figure 7. Relationship between a base shear coefficient C_y=0.4 and a drift angle.

Figures 5, 6 and 7 show seismic damage functions for three base shear coefficients C_y =0.2, 0.3, and 0.4, respectively. Using these seismic damage functions, seismic damage for each base shear coefficient C_y of wooden house can be numerically evaluated against an assumed strong earthquake ground motion.

5 CONCLUSIONS

The evaluation of a site effect is very important in the earthquake engineering when a seismic damage distribution of wooden house will be predicted by an accurate estimation of seismic intensity. In this paper, both horizontal and vertical microtremors at 51 sites in the west district in Maizuru city were measured by servo type accelerometers, and also the predominant periods at 727 sites in the same area were numerically evaluated from the predominant periods measured at 51 sites. Moreover, seismic damage prediction of wooden house against a strong earthquake ground motion with the Japan Meteorological Agency seismic intensity of “5 lower to 6 upper” level was conducted by the relationship between the vulnerability function and the maximum drift angle of wooden house.

The summary obtained in this paper is as follows:

(1) A predominant period at the site without any ground information can be easily evaluated from microtremor *H/V* spectral ratio obtained from microtremor measurement.

(2) Using the Inverse Distance Weighting method, a distribution map of predominant period of ground can be numerically estimated under the limited microtremor observation values.

(3) Vulnerability function with a base shear coefficient can be obtained from the maximum drift angle of wooden house, which is evaluated by the predominant period of ground. Also, collapse rate of wooden house for each base shear coefficient can be predicted by the vulnerability function.

References

Nishikawa, H. and Takatani, T., Evaluation of S-wave Amplification Spectrum using Microtremors in Maizuru City, *Proceedings of the 2nd Australasia and South East Asia Conference in Structural Engineering and Construction* (ASEA-SEC2), 109-114, Bangkok, Thailand, 2014.

Shepard, D., A Two-dimensional Interpolation Function for Irregularly-spaced Data, *Proceedings of the 1968 23rd ACM National Conference*, 517-524, 1968.