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Study on hazard evaluation method for surface ground using response spectrum

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Abstract

The preparation of hazard maps is an effective precautionary measure for earthquake disaster management. To create highly accurate seismic hazard maps, detailed ground information is needed. The most effective method for obtaining detailed ground information is to conduct boring surveys. However, extensive boring surveys are time-consuming and expensive. Therefore, as a technique for obtaining ground information with relative ease, methods using microtremor observation have come into focus.

The authors propose a new ground hazard evaluation method using the predominant period and peak value (amplification factor) of the H/V spectral ratio obtained from single-point microtremor observations. For this study, we assumed that the transfer function of the ground and the H/V spectral ratio of the tremor were almost the same and examined the validity of the ground hazard evaluation method using numerical simulations. Despite some variation due to the ground model and the input earthquake motion, the ground hazard obtained from the transfer function of the ground showed a good correlation with the SI value of the ground surface response result.

Keywords: seismic hazard map, microtremor, H/V spectral ratio, predominant period, amplification factor

1. Introduction

In recent years Japan has been swayed by fears over predictions of very strong earthquakes expected to cause massive damage, specifically a giant earthquake in the Nankai Trough and an earthquake directly under the capital Tokyo. One of the precautionary measures of earthquake disaster management is the preparation of hazard maps. Producing highly accurate earthquake hazard maps requires studies using detailed ground information. In order to obtain detailed ground information, it is common to conduct boring surveys. However, boring surveys for obtaining extensive ground information are expensive and time consuming. Therefore, in recent years techniques using micro tremors for obtaining ground information have come into focus. There are various methods that use micro tremors, such as micro tremor array exploration, which involves simultaneous observation with multiple instruments, and H/V spectral ratio evaluation based on results drawn from a single machine, [for example 1) and 2)]. Moreover, in recent years a concept emerged which considers the application of diffuse field theory to the interpretation of micro tremors[3), 4)].

The authors propose a ground hazard assessment method using the predominant period and its peak value (amplification factor) of the H/V spectral ratio obtained from single-point micro tremor observation[5)]. In this study, it is assumed that the ground motion transfer function and the H/V spectral ratio of the micro tremor are approximately equal. The validity of the ground hazard evaluation method is examined using numerical simulations[6)].

2. Examination method

Although the physical foundation is in part not understood, it is empirically known that when a measure of contrast exists between the base and the surface ground, the H/V spectral ratio of microtremors is relatively consistent with the ground transfer function. Therefore, we propose a method to evaluate ground hazard (PE) by multiplying the predominant period of microtremors with the peak value (amplification factor) (Eq. (1))[5)]. Fig.1. shows an image of the hazard value (PE).

$$PE = Tm \times Rm \tag{1}$$

PE: Hazard evaluation value

Tm: Predominant period (s)

Rm: Peak value (amplification factor)

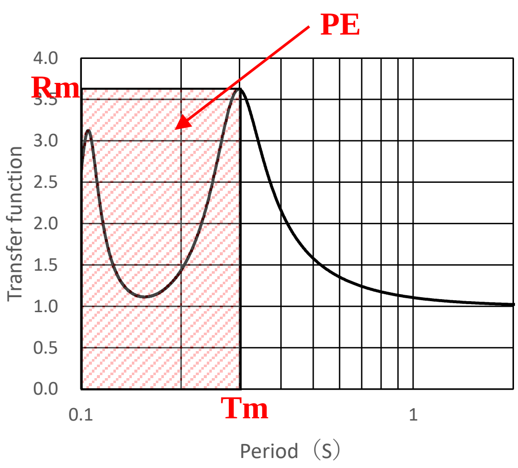


Fig. 1 – Image of the hazard value (PE)

The study method first sets the ground model of the surface and from the transfer function of the surface layer relative to the base reads the predominant period (Tm) and peak value (amplification factor). The hazard evaluation value of the ground is calculated by multiplying the two.

Meanwhile, by changing some input earthquake motions to the created ground model, earthquake response analysis is performed, response spectrum and SI values are calculated from the ground surface response values.

By comparing these hazard values and response values, the validity of the hazard values is examined and considered.

3. Analysis conditions

3.1 Setting of the input earthquake motion

The input earthquake motion used in the earthquake response analysis is the maximum velocity of BCJ-L1 (simulated seismic wave for model design)[7] and the observed waveform of the actual earthquake (Hachinohe, Taft and Elcentro)[8] standardized at 20 kine (cm/s). Fig. 2 shows the acceleration response spectrum of each earthquake motion. Since the study assumes a comparison with the results from the micro tremors, the analysis disregards the non-linearity of the ground, which is taken to be linear.

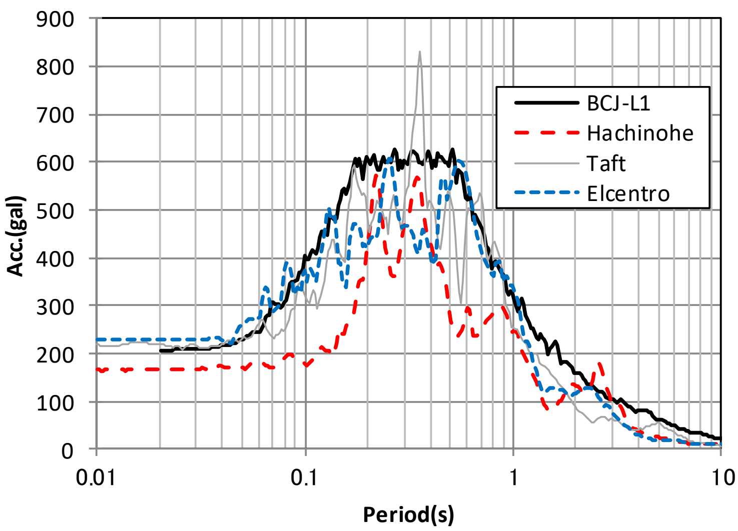


Fig. 2 – Earthquake acceleration response spectrum (h=5%)

3.2 Setting of the ground model

For the ground model, two types of studies were conducted: a virtual ground model and a real ground model, consisting of the actual ground survey result.

For the virtual ground model, two-layer and three-layer grounds were set. For the two-layer ground and the three-layer ground, a model was assumed in which the shear wave velocity of the base layer was 700 m/s and the layer thickness and shear wave velocity of the surface layer subject to regular change.

The two-layered ground was a 16-pattern model with four types of layer thickness and four types of shear wave velocity. Table 1 summarizes the model combinations.

The three-layer ground was a 208-pattern model featuring a three-layer structure with two layers of surface ground, 16 layer thicknesses, and 13 types of shear wave velocity. Table 2 summarizes the layer thickness and shear wave velocity. In order to simplify matters, combinations in which the lower layer is softer than the upper layer (low shear wave velocity) have been omitted (shown in the table as right slash).

As the real ground model, the ground model of the strong-motion observation points implemented by Yokohama City was adopted.[9)] In Yokohama City, strong-motion observations were conducted at 42 locations. The strong-motion observation records and ground information have been made public. Using the ground information of the 42 points, a study was conducted identical to that of the virtual ground. Fig. 3 shows the 42 points and the micro topography classifications[10)]. The observation points are distributed across various terrains such as hills, alluvial lowlands, and landfills.

It is assumed that the damping constant of the surface ground of all models is 1%.

Fig. 4 summarizes the shear wave velocity structure of the ground model. It can be seen that the thickness and shear wave velocity of the two-layer ground and the three-layer ground change regularly. It is also apparent that the real ground features a complicated distribution of structures made up of all kinds of layer thicknesses and shear wave velocities.

Table 1 – virtual ground model (two-layered)

		thickness (m)			
		5	10	20	40
Vs (m/s)	100	①	②	③	④
	150	⑤	⑥	⑦	⑧
	200	⑨	⑩	⑪	⑫
	250	⑬	⑭	⑮	⑯

Table 2 – virtual ground model (three-layered)

		second layer thickness (m)			
		5	10	15	20
first layer thikness (m)	5	①	②	③	④
	10	⑤	⑥	⑦	⑧
	15	⑨	⑩	⑪	⑫
	20	⑬	⑭	⑮	⑯
		second layer Vs (m/s)			
		150	200	250	300
first layer Vs (m/s)	150	(1)	(2)	(3)	(4)
	200	(5)	(6)	(7)	(8)
	250		(9)	(10)	(11)
	300			(12)	(13)

Ex) ②-(3)

first layer : 5m・150m/s

Second layer :10m・250m/s

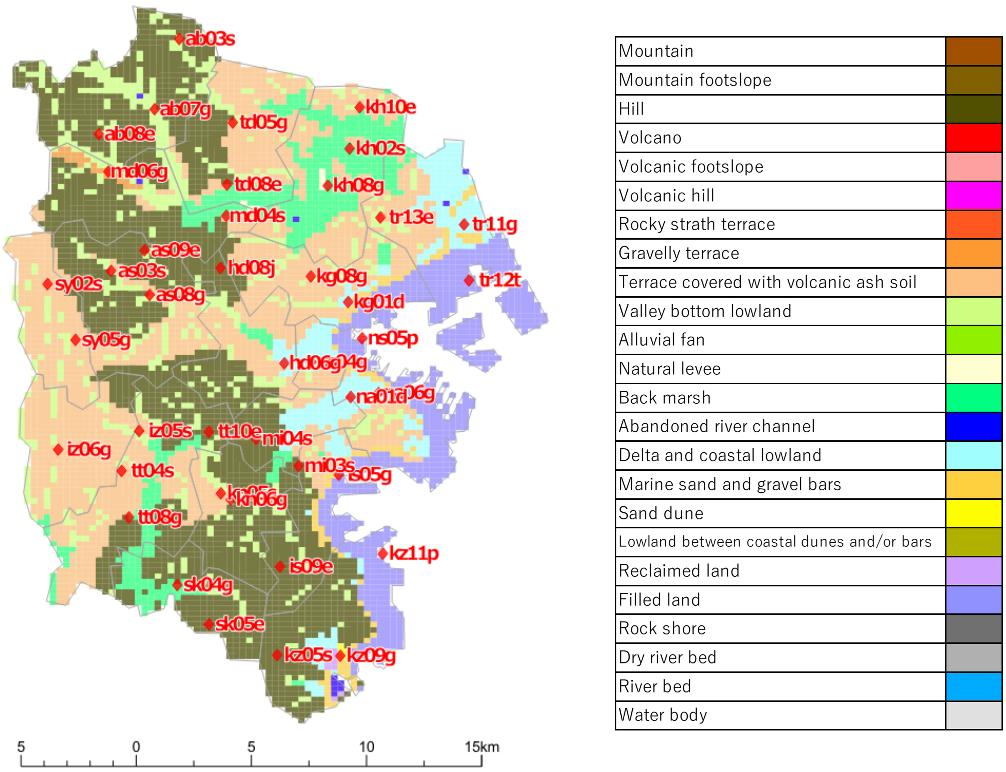
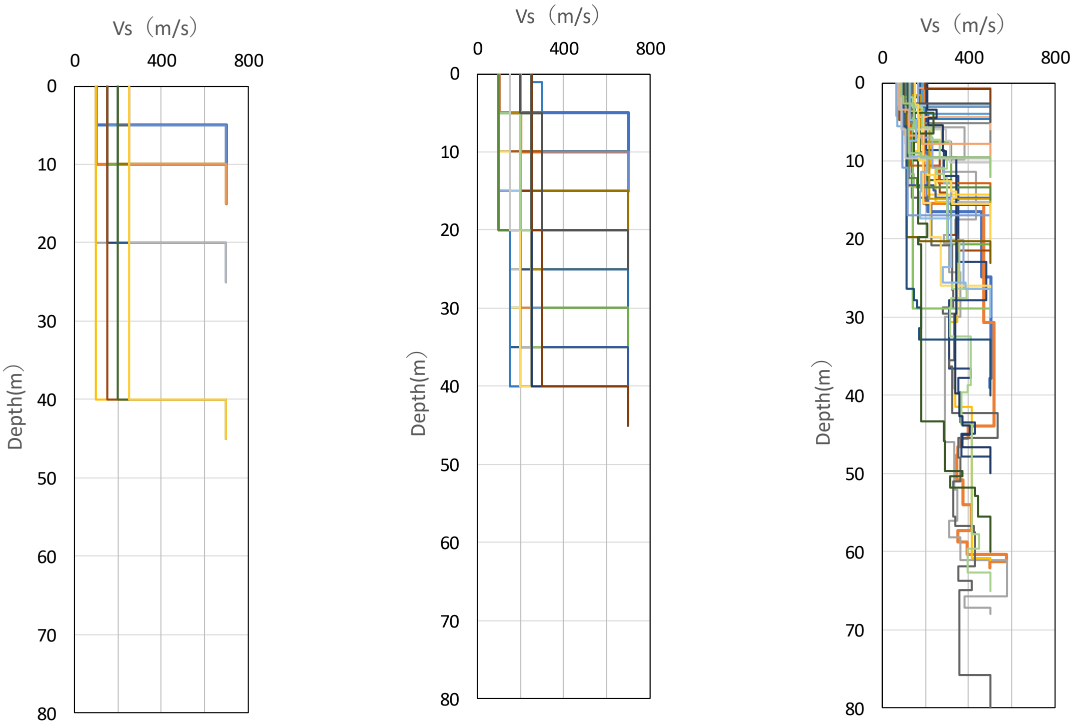


Fig. 3– real ground model point and micro topography classifications



(a) two-layered model (b) three-layered model (c) real ground model

Fig. 4– shear wave velocity structure of the ground model

4. Study results

4.1 Virtual ground (two-layer model) study results

I'm also studying the relationship between the maximum value of the acceleration response spectrum and displacement response spectrum and the hazard value. However, hereafter, the results for the velocity response spectrum and SI value, which have a good correlation with the hazard value, are summarized.

Obtained from the study results of the virtual ground (two-layer model), Fig. 5 and 6 show the relationship between the hazard value (PE) and the maximum value of the velocity response spectrum, and the relationship between the hazard value and the SI value.

The relationship between the hazard value and the maximum value of the velocity response spectrum has some variation due to earthquake motion. However, rising hazard is broadly associated with a rising maximum value of the velocity response spectrum, corroborating a positive correlation. The relationship between the hazard value and the SI value has less variation than the maximum value of the velocity response spectrum, testifying to a solid correlation.

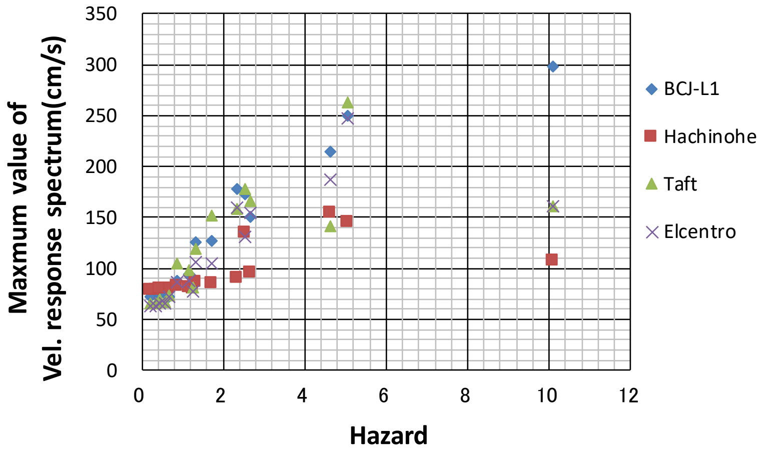


Fig. 5– hazard value and the maximum value of the velocity respons spectrum(two-layer model)

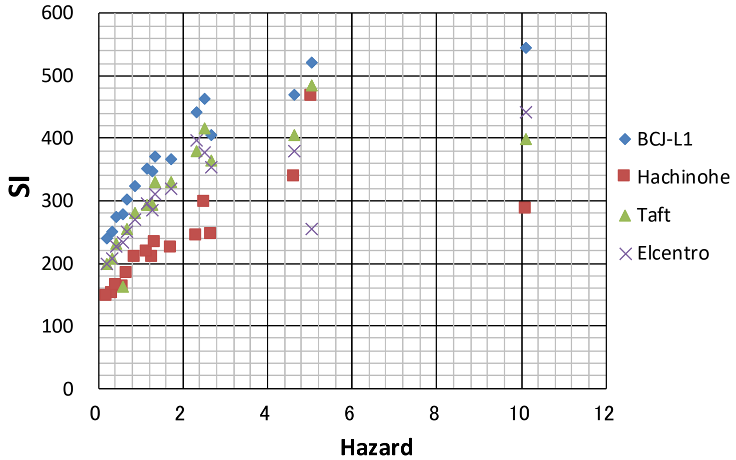


Fig. 6– hazard value and the SI value (two-layer model)

4.2 Virtual ground (three-layer model) study results

Obtained from the study results of the virtual ground (three-layer model), Fig. 7 and 8 show the relationship between the hazard value (PE) and the maximum value of the velocity response spectrum, and the relationship between the hazard value and the SI value.

As with the results for the two-layered ground, overall the rising slope tells of a fairly good correlation. However, the characteristics are partially at variance, depending on the earthquake. In particular, BCJ-L1 separates into two groups up to a hazard value of about 2. Also, the incline of the overall steady ascent flattens when the hazard value exceeds 2.

As a simple method to evaluate the amplification characteristics of the ground, the average value of the S wave velocity (AVS30) of the ground from the surface to a depth of 30 m is used[11),12)]. Therefore, AVS30 of each model was calculated. AVS30 for each model of the three-layer ground is shown in Fig. 9, the hazard value is shown in Fig. 10, and the relationship between the two is shown in Fig. 11. Although the variation is somewhat large, the negative correlation of decreasing AVS30 and rising hazard value is in evidence. The correlation by an approximate curve (logarithmic approximation) is high.

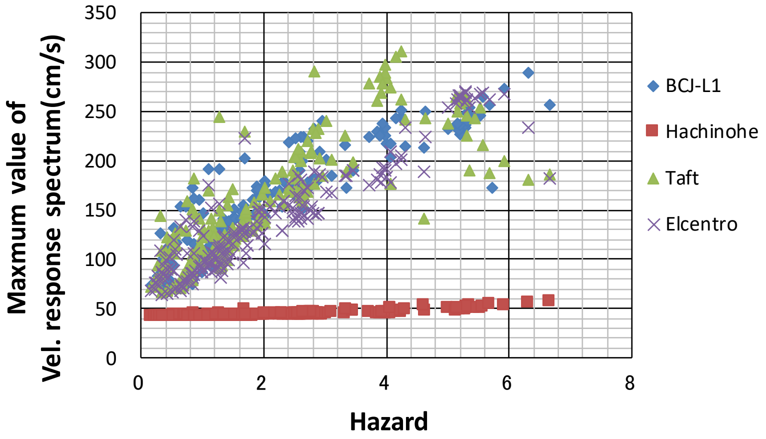


Fig. 7– hazard value and the maximum value of the velocity respons spectrum (three-layer model)

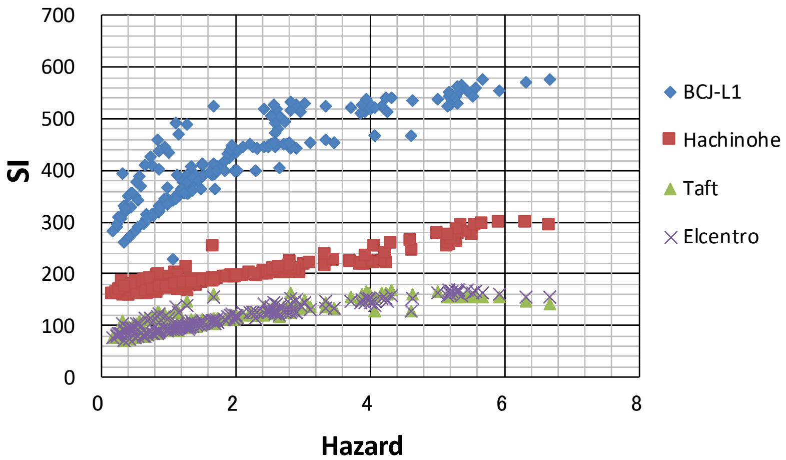


Fig. 8– hazard value and the SI value (three-layer model)

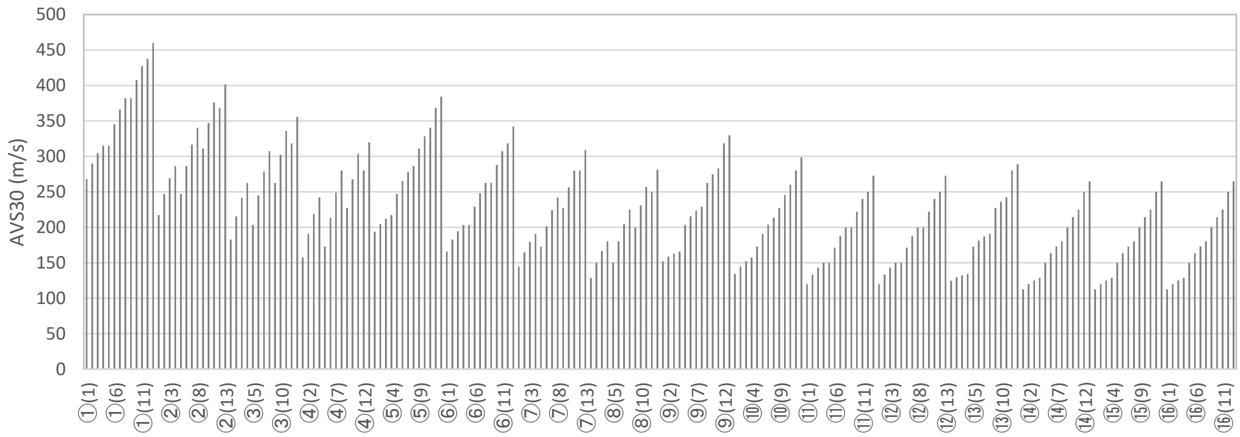


Fig. 9– AVS30 for each model (three-layer model)

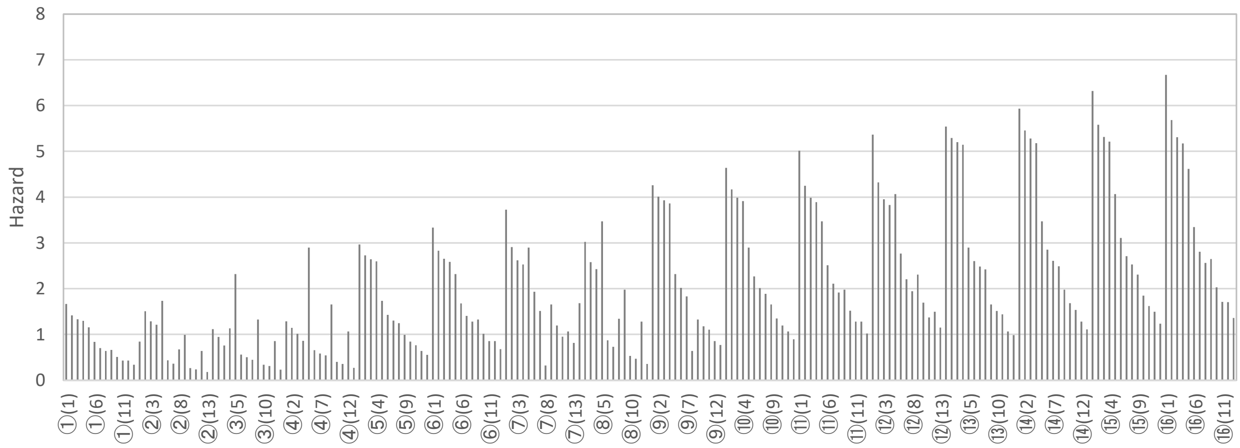


Fig. 10– hazard value for each model (three-layer model)

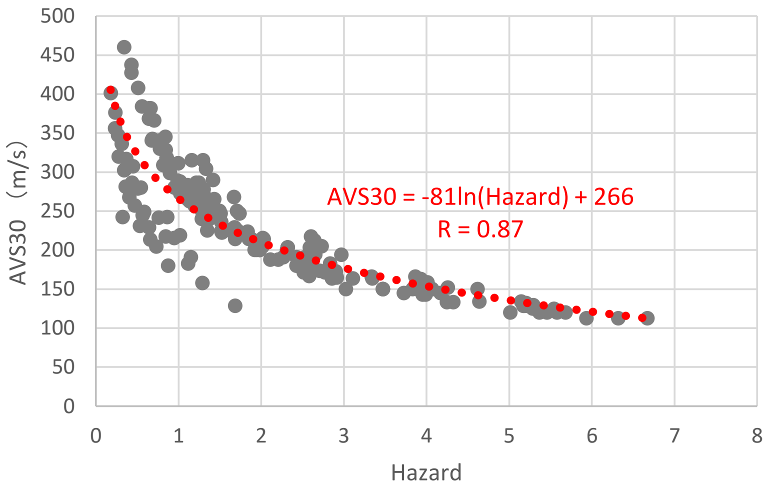


Fig. 11– hazard value and the AVS30 (three-layer model)

4.3 Real ground study results

Obtained from the study results of the real ground, Fig. 12 and Fig. 13 show the relationship between the hazard value (PE) and the maximum value of the velocity response spectrum, and the relationship between the hazard value and the SI value.

Overall the graph shows a steady ascent largely in line with the virtual ground, but variation is somewhat higher. The slope tends to flatten when the hazard value exceeds the range of 3 to 4, which is also consistent.

The cause of the variation, unlike with the virtual ground, is considered to be due to the heterogeneity of the ground.

Fig. 14 shows the real ground model's AVS30, Fig. 15 shows the hazard value, and Fig. 16 shows the relationship between the two. As with the three-layer ground, despite some variation, the negative correlation of decreasing AVS30 and rising hazard value is in evidence. Similar to the three-layer model, the correlation by the approximate curve (logarithmic approximation) is high.

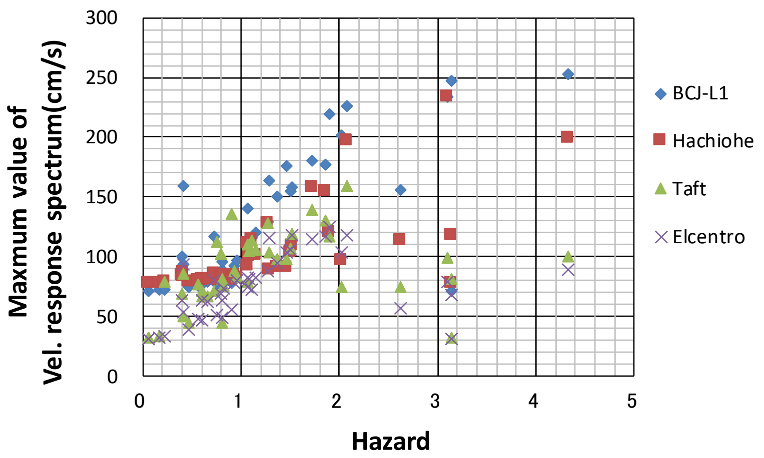


Fig. 12– hazard value and the maximum value of the velocity respons spectrum (real ground model)

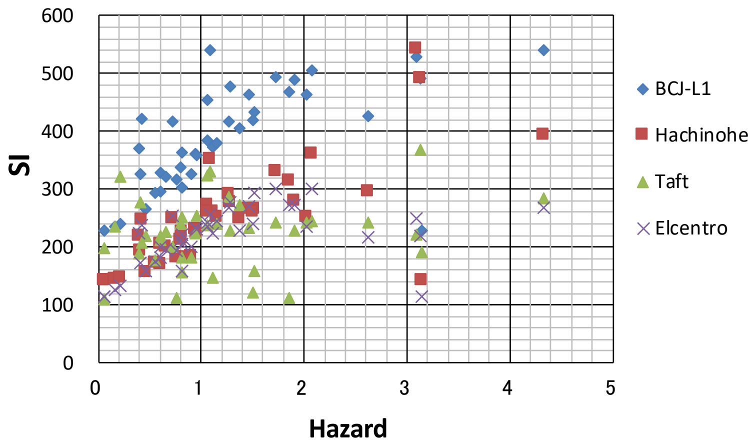


Fig. 13– hazard value and the SI value (real ground model)

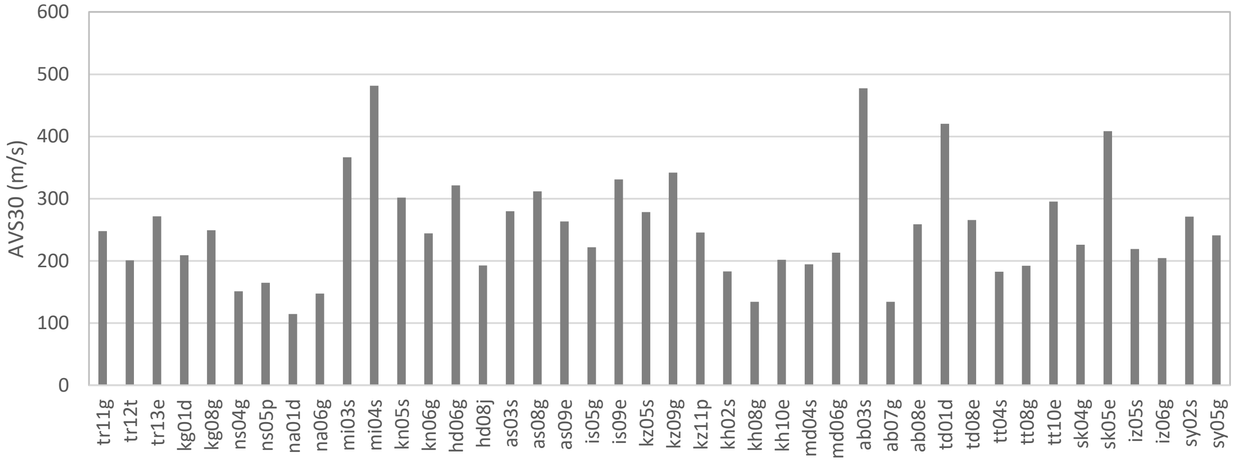


Fig. 14– AVS30 for each model (real ground model)

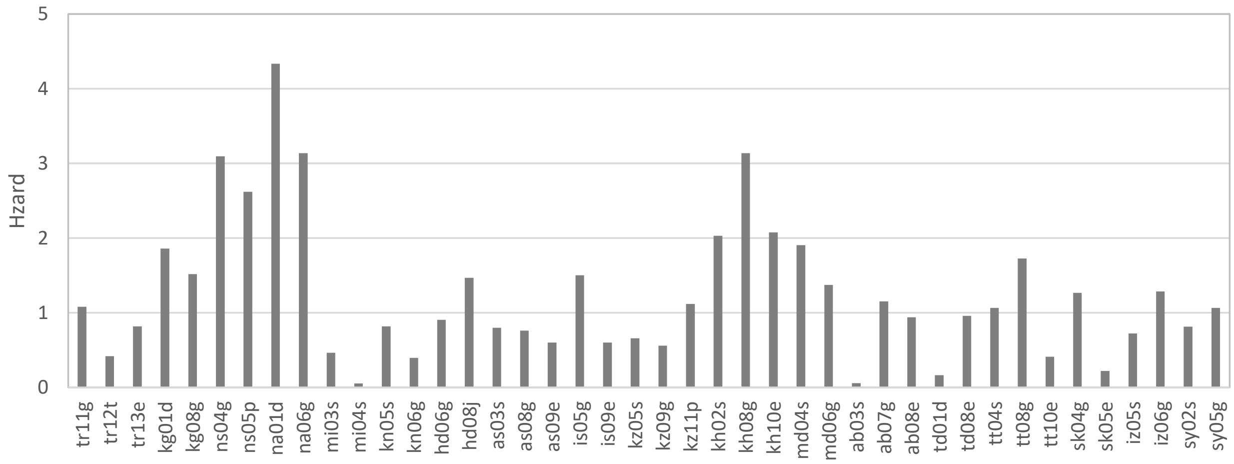


Fig. 15– hazard value for each model (real ground model)

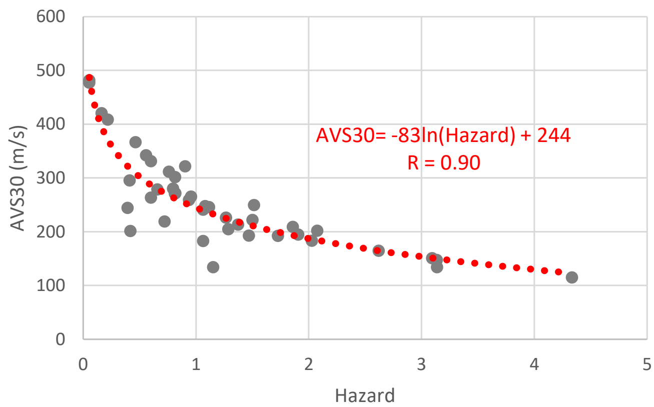


Fig. 16– hazard value and the AVS30 (real ground model)

5. Summary and Discussion

The study examined the hazard values obtained from the ground transfer function, and the maximum value and SI value of the velocity response spectrum obtained from the ground surface response by earthquake response analysis. The study was carried out for virtual ground and real ground models. Overall good correlations with steady ascents were in evidence for all ground models.

However, results also showed a tendency of rising hazard evaluation values combining with flattening inclines (that is, the hazard value increases although the SI value remains constant). Attention is required when a hazard value reaches or rises above a reading of 2.

The study compared AVS30 and hazard values between the virtual model 3-layer ground and the real ground model. Both models showed rising hazard values associated with falling AVS30. In addition, a high correlation was confirmed for the approximate curve (logarithmic approximation).

In the future, we plan to test for consistency between the H/V spectral ratio of micro tremors and the transfer function of the ground, and will consider evaluation methods for large hazard values, among other subject matter.

6. References

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