ESTIMATION OF STRONG MOTION USING H/V SPECTRAL RATIO OF MICROTREMOR OBSERVATION DURING THE 2018 HOKKAIDO EASTERN IBURI EARTHQUAKE, JAPAN

A. Murata [(1)], R. Ohno [(2)], M. Miyajima [(3)]

[(1)] *Assistant Professor, College of Geoscience and Civil Engineering, Kanazawa University, murata@se.kanazawa-u.ac.jp*
[(2)] *Graduate Student, Graduate school of Natural Science and Technology, Kanazawa University, ryu0613@stu.kanazawa-u.ac.jp*
[(3)] *Professor, College of Geoscience and Civil Engineering, Kanazawa University, miyajima@se.kanazawa-u.ac.jp*

Abstract

The damage estimation by an earthquake is required in the earthquake strong ground motion characteristic, the foundation dynamic characteristics of an object area, and the structural characteristic. However, it is difficult to evaluate earthquake strong ground motion simply because much information such as data of standard penetration test is required. There is a method using the horizontal-to-vertical (H/V) Fourier spectral ratios of microtremor observations as one of the method which evaluates an earthquake motion. Because this method is very easy and it is effective, there are many researches by Maruyama et al. (2001) and Okuma et al. (2002), for example. Previous studies are assumed that the microtremor H/V spectral ratio between a presuming point and an observation point is relative amplification because the microtremor H/V spectral ratio and seismic H/V spectral ratio is similar, and the vertical spectral characteristic of a presuming point and an observation point is similar. But accuracy of presumption has some problems. And evaluation of earthquake strong ground motion in near observation point where ground foundation characteristics is different is not enough. In this study, the method using the H/V Fourier spectral ratios of microtremor observations whose presumed accuracy improved is proposed. Improving parameters are collection coefficient α, β and γ. α is coefficient of maximum amplitude, β is coefficient of predominant period and γ is coefficient of vertical amplitude. And the method takes into account of an attenuation relation for strong earthquake motions. In addition, the fatigue response spectrum intensity (FSI) of having taken the repetition of earthquake motion into consideration is used as an index for evaluating the estimation of strong ground motion. By verifying this estimation method, we use the 2018 Hokkaido Eastern Iburi Earthquake, Japan. We perform microtremor observations in these stations. As a result, there is a certain correlation between the estimation of strong ground motion and the building damage. Therefore, we are able to perform accurately estimation of earthquake strong ground motion.

Keywords: Estimation of Strong Motion, Microtremor Observation, 2018 Hokkaido Eastern Iburi Earthquake

1. Introduction

Major earthquakes that occur frequently in Japan cause enormous damage to buildings especially near the epicenter. Recent studies have reported that the damage is "local rather than uniform, and there are places where the degree of damage to buildings varies in some places in relatively small areas." Such variation in building damage was also observed in the Kumamoto earthquake that occurred in April 2016. Since the buildings near the epicenter of the Kumamoto earthquake are similar in age and structure, it is unlikely that there is a large difference in the strength of the buildings. Therefore, it is considered that the seismic external force acting on the building greatly contributes to the dispersion of the building damage. In addition, it was reported that the Hokkaido Eastern Iburi Earthquake that occurred in September 2018 caused less damage to buildings than other earthquakes of the same size that occurred before that. The damage to the building is somewhat affected by the regional differences in the strength of the building, but is considered to be greatly affected by the difference in the external force acting on the building. From the above, it can be said that grasping the seismic external force at high density is important and effective in reducing earthquake damage.

Therefore, in this study, the target area is the Mukawa district (Mukawa-cho, Yufutsu-gun), which is located near the epicenter of the Hokkaido Eastern Iburi Earthquake and where multiple building damages have been reported. The purpose is to perform high-density strong ground motion estimation using microtremor observation records, calculate strong ground motion intensity from the estimated strong ground motion using various indexes, and evaluate the correlation with actual building damage.

2. The Method of Estimation Strong Ground Motion Using a Microtremor H/V Spectral Ratio

2.1 Overview of the Method

The H/V spectrum ratio is calculated from the microtremor observation data. The Fourier spectrum of the horizontal strong ground motion at the estimation point is obtained using the estimation formula incorporating the distance correction. It is transformed into an earthquake waveform by inverse Fourier transform. The H/V spectrum ratio and the strong ground motion estimation formula are described in detail below.

2.2 About Microtremor Observation

One of the major effects on earthquake damage is the strong ground motion characteristics of the target area. In recent years, a lot of information has been obtained from various strong ground motion measurement networks (K-NET, KiK-net) in Japan as a method to grasp the ground dynamics. However, the spatial density of the seismometer installation is still low, and it is very difficult to grasp the distribution of ground dynamics with high density. On the other hand, although microtremor observation is less accurate than strong ground motion observation, it is possible to obtain high-density observation results easily and economically, as long as observation equipment is used, regardless of the time and place at which it is performed. Therefore, in this study, we estimate the strong ground motion using microtremor observation.

Microtremor observation were made in the Mukawa district during the daytime on October 1 and 2, 2018. Total of 12 measurements were made, including the strong motion station K-NET Mukawa, in an area of about 1000 m square. The observation time is 20 minutes per point, and the sampling frequency is 100 Hz.

2.3 Evaluation of Microtremor H/V Fourier Spectral Ratio

In this study, we extract more than 5 units from 4096 stable data (40.96sec) as 1 unit using microtremor observation data, 1 unit consists of three components (N-S, E-W and U-D components). These data files are converted using FFT. The converted data are summed and averaged to reduce the effect of noise. It is smoothed using a Parzen window with a bandwidth of 0.8 Hz. The H/V spectrum ratio is calculated by dividing the horizontal component by the vertical component using the synergistic mean value of the N-S and E-W components and the value of the U-D component for the vertical component.

2.4 The Method of Estimation Strong Ground Motion

2.4.1 Overview of Estimation Strong Ground Motion

The strong ground motion estimation in this study uses the method of Matsumura et al.[1]. This method is based on the earthquake motion estimation method formulated by Harada et al.[2]. It takes into account as much as possible the observed facts such as "The H/V spectral ratios of strong ground motion and microtremor are not completely equal. The spectral characteristics of vertical strong ground motions are different even when the distance between the two sites is close." In this study, distance attenuation correction α, amplification correction β and period correction γ are introduced when estimating strong ground motion. The horizontal Fourier spectrum at the estimation point is H_E^E, and an estimation formula is shown Eq. (1).

$$H_E^E = \alpha \cdot \frac{\beta_O}{\beta_E} \cdot \gamma_{E/O} \cdot \frac{1/c_{Emax} (H/V)_E^M}{1/c_{Omax} (H/V)_O^M} \cdot H_O^E \tag{1}$$

Thus, The subscript represents the observation point, and the strong motion observation point is distinguished by O, and the estimation point is distinguished by E. c_{Omax} and c_{Emax} represent the maximum values of the microtremor H/V spectral ratio. α, β and γ are distance attenuation correction, amplification correction and period correction, respectively. The details of α, β and γ are described below.

2.4.2 Distance Attenuation Correction α

The distance attenuation correction formulated by Kamiyama[3] is used. The formula is shown in Eq. (2).

$$\begin{aligned} a_{max} &= 547.6 \times 10^{0.358M} \times r^{-1.64} \\ r &= R + 10^{0.014+0.218M} \\ \alpha &= \frac{(a_{max})_E}{(a_{max})_O} \end{aligned} \tag{2}$$

Thus, M is the magnitude, r is the distance from epicenter, and R is the shortest distance from the earthquake fault line. The shortest distance between the reference point and the estimated point is obtained from the earthquake fault line, and the maximum acceleration is calculated from above, and the ratio is taken and used as a coefficient. For the earthquake fault, the one estimated by Geographical Survey Institute is used.

2.4.3 Amplification Correction β

A correction coefficient is defined as shown in Eq. (3) so that the H/V spectrum ratio between the seismic motion and the microtremor is matched. β_o and β_E cannot be calculated without the microtremor observation record and the strong motion observation record of the estimation point and the observation point. K-NET Mukawa strong motion observation records are used as the strong ground motion observation records at each estimated point in the Mukawa district. The values of β_o and β_E are average values in the period of 0.1 second to 2 seconds. The correction factor is defined to match the H/V spectral ratio of the strong ground motion and the microtremor as follows.

$$\beta_O = \frac{1/c_{Omax} (H/V)_O^M}{(H/V)_O^E} \quad , \quad \beta_E = \frac{1/c_{Emax} (H/V)_E^M}{(H/V)_E^E} \tag{3}$$

Thus, β_o and β_E cannot be calculated without microtremor observation records and strong motion observation records of the estimation point and the observation point. Strong motion observation records of K-NET Mukawa are used for the strong ground motion observation records of each estimation point in the Mukawa district. The values of β_o and β_E are average values for a period of 0.1 second to 2 second.

2.4.4 Period Correction γ

The model formulated by Nakamura et al.[4] is used for $\gamma_{E/O}$. The formula is shown in Eq. (4).

$$\gamma^{I}_{E/O} = \left(\frac{1-c'_{max}}{2}\right)\left[\frac{e^{\left[T/T_g-1\right]}-e^{-\left[T/T_g-1\right]}}{e^{\left[T/T_g-1\right]}+e^{-\left[T/T_g-1\right]}}\right] + \left(\frac{c'_{max}+1}{2}\right) \text{ , } \gamma^{II}_{E/O} = \frac{1}{\gamma^{I}_{E/O}}$$

$$T_g = MAX(T_O, \ T_E) \tag{4}$$

$$c'_{max} = \gamma_{E/O}(90\%) = 1.2 \times c_{max} + 1.6$$

$$c_{max} = MAX\left(\frac{c_{O_{max}}}{c_{E_{max}}}, \frac{c_{E_{max}}}{c_{O_{max}}}\right)$$

Thus, the vertical earthquake motion spectrum ratio is $\gamma^{I}_{E/O}$ when the ground of the observation point is hard, and the vertical earthquake motion spectrum ratio is $\gamma^{II}_{E/O}$ when the ground of the observation point is soft. The peak period of the microtremor H/V spectrum ratio of the soft ground is T_g. T_O and T_E represent the peak period of the microtremor H/V spectrum ratio, and C_{Omax} and C_{Emax} represent the maximum value of the amplitude of the microtremor H/V spectrum ratio, respectively. For C_{Omax} and C_{Emax}, the maximum value of the amplitude in the period of 0.1 second to 2 second is set, and the period at that time is set to T_O and T_E, respectively.

3. Evaluation of Earthquake Damage Estimation Index

In addition to conventional indices such as the peak ground velocity (PGA) and the seismic intensity, the fatigue response spectral index (FSI value[5]) considering the repetition of the seismic response is used to evaluate the seismic damage of houses using the earthquake motion. An overview of FSI values is given below. The concept of the FSI velocity value is shown in Fig. 1. The FSI value is expressed three-dimensionally with the period range as T = 0.1 ~ 2.5 (s). That is to say, the natural period of the building is represented on the X axis, the velocity response spectrum (S_v) on the Y axis, and the number of repetitions (C_{S_v}) at each response level on the Z axis. For example, the number of iterations at the point where the velocity response spectrum is multiplied by 0.4 in the natural period corresponds to the number of iterations at 40% of the velocity response waveform. By the above method, the volume obtained by integrating the number of repetitions with the response spectrum, i.e., the integrated value of the fatigue response rate spectrum, is obtained. Energy is expressed as the product of mass and velocity squared. Then, the value obtained in the integration is multiplied by the square of the velocity response spectrum so as to express the maximum energy given to the structure by the earthquake motion, and the value obtained by this is called the FSI velocity value. The FSI velocity value is given by Eq. (5).

$$FSI_v = \int_{0.1}^{2.5} \int_{0.01S_v}^{S_v} C_{S_v} {S_v}^2 \, dS_v dT \tag{5}$$

Thus, T is a period, S_v is a velocity response spectrum, and C_{S_v} is a repetition number.

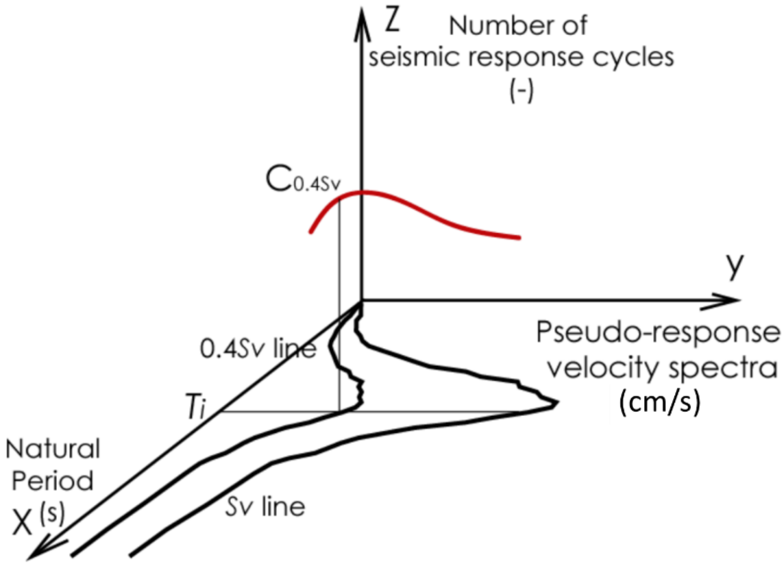

Fig. 1 – Concept of the FSI velocity value

4. Verification of the Validity the Method of Estimation Strong Ground Motion

We estimate strong ground motions in Mukawa district during the 2018 Hokkaido Eastern Iburi Earthquake. Matsumura's estimation method has been confirmed to be highly accurate in the 2016 Kumamoto earthquake. It is necessary to confirm whether the method can be applied to the 2018 Hokkaido Eastern Iburi Earthquake. Therefore, the validity of the estimation method for this earthquake is confirmed by comparing the observation results of the Mukawa district with the estimation results. The estimation point is K-NET Mukawa and the reference point is Atsuma Town Office. Fig.2 shows the positional relationship between each point and the epicenter. To calculate the estimated acceleration waveform, the phase information of the observation record is used without considering the phase characteristics of the estimated point. Therefore, it is not possible to evaluate the shape of the seismic waveform. Therefore, the validity is verified by frequency characteristics such as acceleration Fourier spectrum and seismic motion evaluation indexes such as PGV and measured seismic intensity.

Fig. 3 shows a comparison of frequency characteristics with the acceleration Fourier spectrum. It can be seen that the spectral waveforms are out of phase around 1 second in period, but the characteristics are similar. Table 1 shows the comparison of the seismic motion evaluation index. Comparing the estimation results with the observation records, the PGA is slightly different. However, the PGV and the measured seismic intensity almost match.

From this verification, it was confirmed that the accuracy of the K-NET Mukawa strong ground motion estimation based on the Atsuma Town Office was generally valid. It is said that the damage of buildings due to shaking has a high correlation with the PGV, so it is useful to estimate the strong ground motion using this method in considering the damage situation. Therefore, we use the records of the Atsuma Town Office as a reference point for the strong ground motion estimation in the Mukawa district in this study.

Fig. 2 – Positional relationship between each point and the epicenter

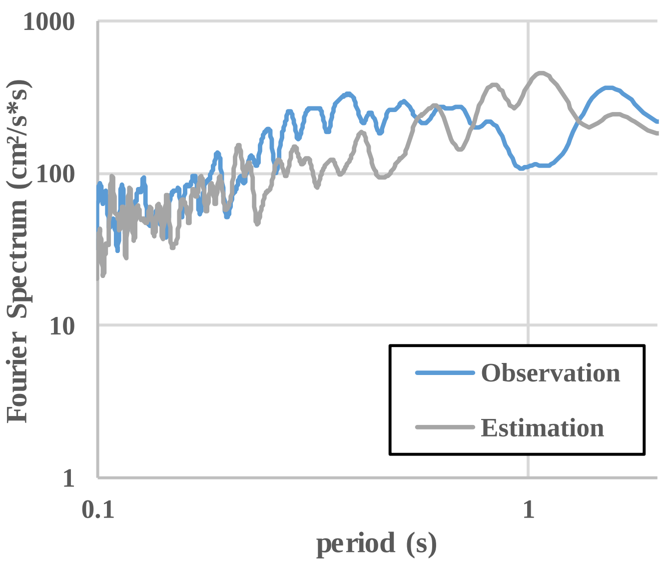

Fig. 3 – Comparison of acceleration Fourier spectrum between observation and estimation

Table 1 – Comparison of the seismic motion evaluation index between observation and estimation

	PGA (cm²/s)	PGV (cm/s)	JMA Seismic Intensity
Observation	662	48	6.4
Estimation	482	68	6.2

5. Results and Consideration of Seismic Motion Estimation in Mukawa District

Table 2 shows the results of strong ground motion estimation at 12 microtremor observation points in the Mukawa district using PGV, measured seismic intensity, and velocity FSI. Fig. 4, 5, and 6 show the strong ground motion distribution for each evaluation index. Fig. 7 shows the damage ratio of buildings around each estimation point. The damage ratio used here is based on an exhaustive survey by Okada et al.[6]. Here, the damage ratio is the proportion of buildings judged to be more than partially damaged among all buildings.

The distribution of the strong ground motion shows a similar tendency for all the evaluation indices. Point 7 takes the maximum value, followed by point 11, and the surrounding areas point 6, 8, 10, and 22 also show large values. However, point 21 is not so large. On the other hand, point 19 and 20 show particularly small values, and the surrounding point 4, 5, and 9 also show small values. Overall, the estimated strong ground motions in the Mukawa district tend to be large in the west and small in the east.

The damage ratio is large at point 7, 8, and 6 in the west, and small at point 9 and 10 in the east. Also, point 21 shows a small value. This characteristic is common to the estimated strong ground motion. On the other hand, unlike the estimated strong ground motion, point 10 is small and 11 is large. However, it is possible to judge that there is a tendency of west high east low. Thus, it can be said that there is a certain correlation between building damage and estimated strong ground motion.

Table 2 – Estimation results at 12 points in the Mukawa district using evaluation indices

Point No.	PGV (cm/s)	JMA Seismic Intensity	FSIv ($\times 10^3$) (cm^2/s)	Damage Ratio (%)
4	67.7	6.2	8.7	35
5	70.2	6.3	10.2	33
6	103.4	6.4	19.3	47
7	139.2	6.6	36.9	60
8	113.2	6.5	24.0	67
9	51.4	6.0	5.1	0
10	105.8	6.5	21.6	0
11	117.5	6.7	33.8	33
19	38.1	5.7	2.8	20
20	45.9	5.9	3.9	35
21	84.4	6.3	14.1	0
22	104.4	6.5	20.9	22

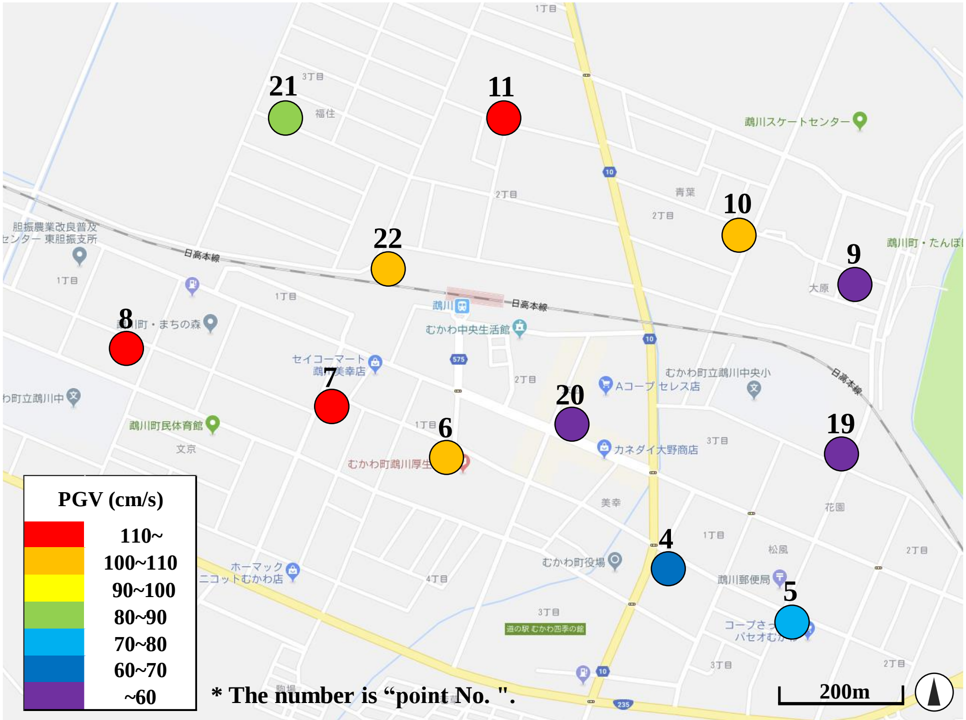

Fig. 4 – Distribution of estimation (PGV)

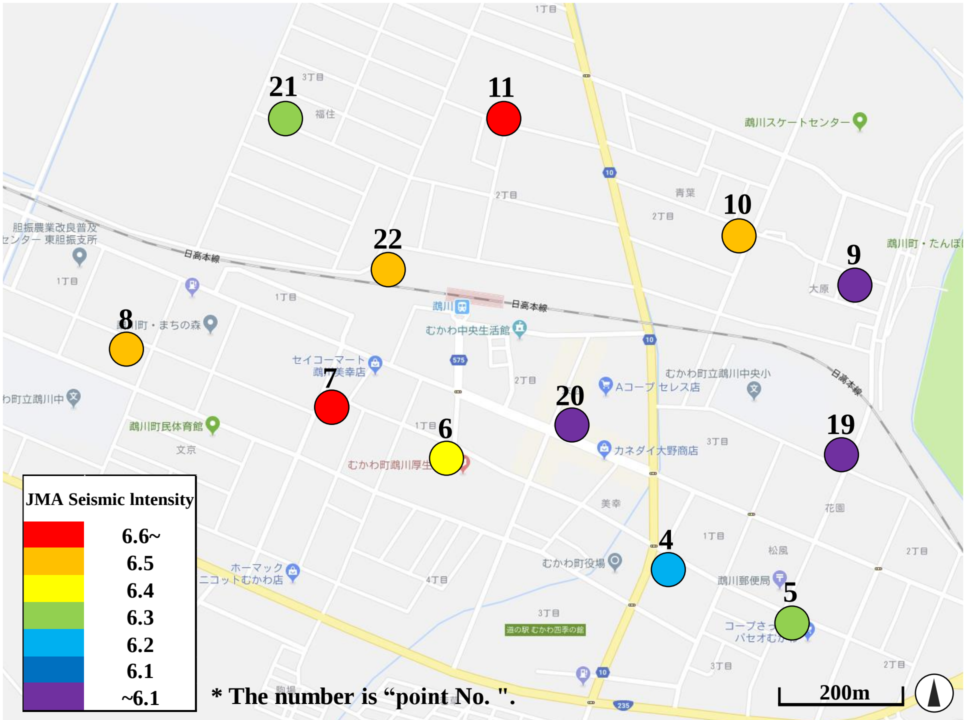

Fig. 5 – Distribution of estimation (JMA Seismic Intensity)

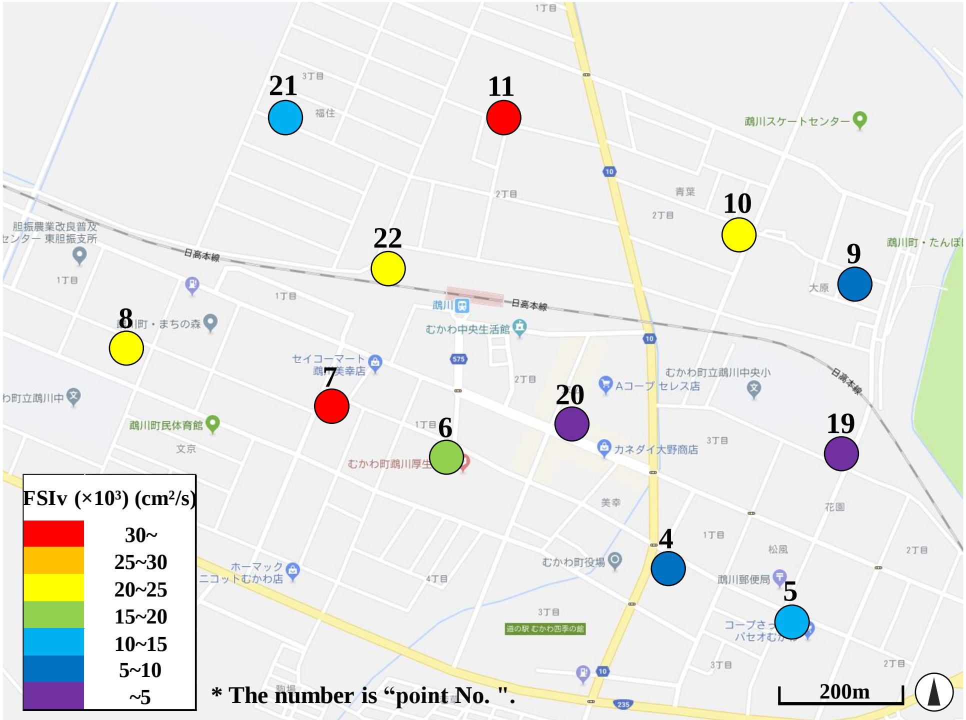

Fig. 6 – Distribution of estimation (FSIv)

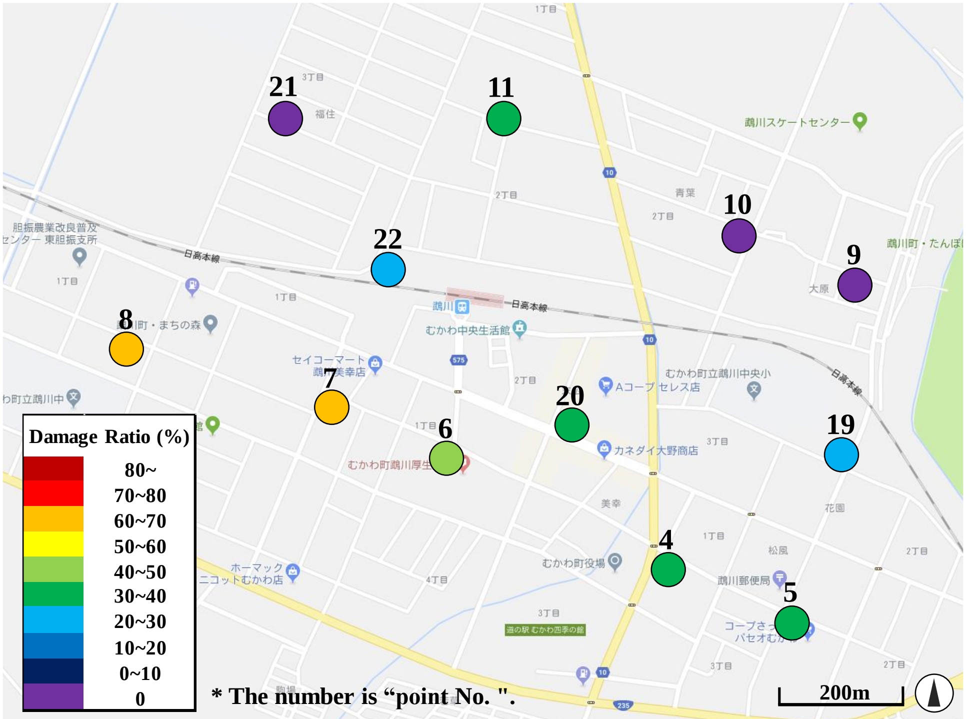

Fig. 7 – Distribution of damage ratio

6. Conclusions

The conclusions of this study are summarized below.

1) Sufficient accuracy was obtained when the seismic motion in the Mukawa district was estimated using the Atsuma Town Office as a reference point.

2) The results of expressing 12 estimated strong ground motions in the Mukawa district with various strong ground motion evaluation indices showed that there was a tendency of west high east low.

3) According to the comparison between the estimated strong ground motion and the damage to the building, a certain correlation could be confirmed with some exceptions.

Acknowledgements

In this study, we used the strong motion records of K-NET and Atsuma Town Office. I express my gratitude here.

References

[1] Matsumura N, Murata A, Hata Y, Miyajima M (2018): Estimation of the Earthquake Strong ground motion Using Microtremor Observation. Annual Meeting of the Chubu branch of Japan Society Civil Engineers, CD-ROM. (in Japanese)

[2] Harada T, Nakamura M, Wang H, Saitoh S (2008): A Method of Estimation of Earthquake Ground Motion Using Nearby Records and Microtremors H/V Spectral Ratio. Journal of applied mechanics, Vol.11, pp.595-602. (in Japanese)

[3] Kamiyama M, Matsukawa T (1997): Wave Interpretation of Strong Ground Motions Obtained During The 1995 Hyogoken Nanbu Earthquake. Journal of JSCE, No.586 / III -39, 49-66. (in Japanese)

[4] Nakamura M, Harada, Ichimura A, Wang H, Saitoh S (2009): A Method of Estimating Earthquake Ground Motion Using Microtremor H/V Spectral Ratio. JSCE Journal of Earthquake Engineering, Vol.30, Ser. A1, 65-74. (in Japanese)

[5] Murata A et al. (2000): Prediction of damage to wooden houses by using fatigue response spectra considering number of seismic response cycles. Proceedings of 12th World Conference on Earthquake Engineering, No.1870, 6p.

[6] Okada S et al. (2019): Resilience and new problems of houses in cold regions in the snow in the eastern part of the Hokkaido Iburi Earthquake. Institute of Scientific Approaches for Fire & Disaster All, No.138. (in Japanese)

