RELATIONSHIP BETWEEN SEISMIC INTENSITY AND DRIVERS' REACTION BASED ON QUESTIONNAIRE SURVEY

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SUMMARY

The relationship between the seismic intensity and the reactions of expressways drivers were investigated based on the questionnaire survey conducted by Japan Highway Public Corporation (JH) after the Sanriku-Minami earthquake, which occurred on May 26, 2003. The distribution of seismic intensity was estimated using 132 earthquake records at K-NET stations and 52 records at JH stations. Kriging technique was employed to obtain the spatial distribution of seismic intensities. The results of the questionnaire survey were evaluated with respect to the estimated seismic intensity along the expressways. Only 40 % of drivers were aware of the earthquake in the areas where the Japan Meteorological Agency (JMA) seismic intensity is smaller than 4.0. On the contrary, more than 80 % of drivers recognized the earthquake in the areas where the JMA seismic intensity is larger than 4.5. The abnormal vibration of the vehicle was indicated as the reason why the drivers recognized the earthquake. Hence, the seismic motion is considered to affect safe and stable driving.

INTRODUCTION

The number of automobiles in Japan is increasing year by year, and it is larger than 77 million including motorcycles [1]. It is supposed that many people are driving just when a large earthquake occurs. As the demand for highway traffic increases, safety requirements for highways significantly increase even at the time of an earthquake [2]. Therefore, it is important to realize the response characteristics of automobile drivers during an earthquake.

Kawashima *et al.* [3] have conducted the questionnaire survey for the drivers who were driving during earthquakes. The survey revealed that some drivers mistakenly interpreted the earthquake as a tire blowout, and they could not control the steering wheel properly due to abnormal vibration. The presented authors have conducted the driving simulator experiments to reveal the drivers' response characteristics when they are subjected to strong shaking [4]. Based on the results, the drivers protrude their running lane. Hence, they might be involved in an accident because of strong shaking.

Japan Highway Public Corporation (JH) had deployed the seismometer network to make an efficient traffic control just after an earthquake [5]. Hence, it is expected that the distribution of seismic intensity along the expressway can be obtained.

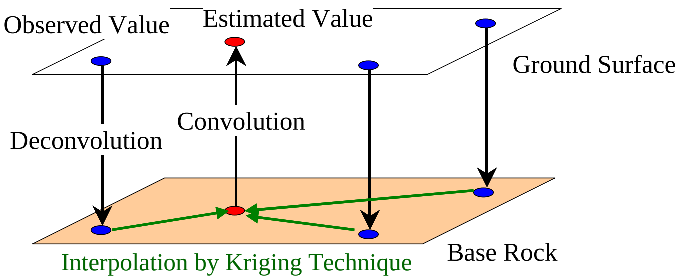


Figure 1. Schematic figure for interpolation of strong motion indices

In this study, the distribution of seismic intensity for the Sanriku-Minami earthquake, which occurred on May 26, 2003 (JMA Magnitude is 7.0), is estimated based on Kriging technique [6]. The results of the questionnaire survey conducted by JH are compared with the estimated seismic indices.

ESTIMATION OF THE DISTRIBUTION OF SEISMIC INDICES BASED ON KRIGING TECHNIQUE

Kriging technique, a method of stochastic interpolation, is employed to estimate the spatial distribution of ground motion indices from recorded values. In Kriging technique, observed values are realized at the observation points. Between the observation points, stochastic interpolation consisting of the trend (mean) and random components gives an estimation of the spatial distribution [7]. In this study, 132 ground motion records at K-NET seismic observation stations, which were deployed by National Research Institute for Earth Science and Disaster Prevention, and 52 ground motions recorded at JH seismic observation stations are used for the estimation of the spatial distribution of the peak ground acceleration (*PGA*) and the JMA seismic intensity (*I*).

Figure 1 shows the schematic figure for interpolation of strong motion indices performed in this study. Since the earthquake motion on the ground surface is affected by amplification characteristics of subsurface layers, the interpolation should be carried out at the (outcrop) base as shown in Fig. 1. The amplification ratios estimated from attenuation relationships [8] are used for the seismic indices of K-NET records, and those estimated from the digital national land information of Japan [9] are used for JH records. Then, the recorded seismic indices at the ground surface (PGA_{si} and I_{si}) are converted to those at the base by Eq. (1) and (2).

$$PGA_{bi} = PGA_{si} / ARA_i \tag{1}$$

$$I_{bi} = I_{si} - ARI_i \tag{2}$$

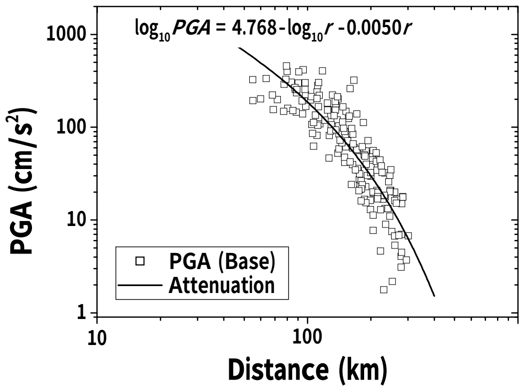
where PGA_{bi} and I_{bi} are the PGA and JMA seismic intensity at the base, respectively. ARA_i and ARI_i are the amplification ratios for PGA and JMA seismic intensity, respectively.

Based on the seismic indices at the base, the attenuation relations are constructed. These attenuation relations are used as the trend component of Kriging. The relations obtained in this study are

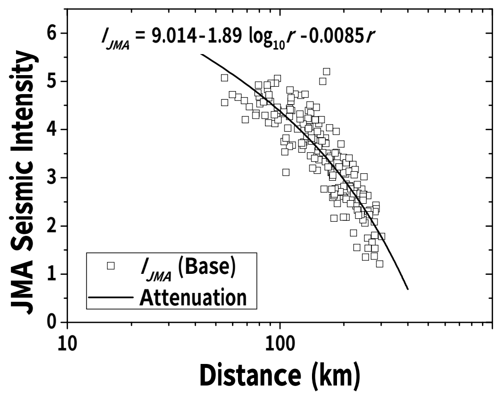
$$\log_{10} PGA = 4.768 - \log_{10} r - 0.0050r \tag{3}$$

$$I = 9.014 - 1.89 \log_{10} r - 0.0085r \tag{4}$$

where r is the shortest distance (km) to the fault rapture. Figure 2 shows the attenuation relationships of PGA and JMA seismic intensity at the base.



(a) PGA



(b) JMA seismic intensity

Figure 2. Attenuation relationships of PGA and JMA seismic intensity at the base in the 2003 Sanriku-Minami earthquake

In the Kriging technique, a spatial auto-correlation function should be assigned. An exponential function is employed in this study. The correlation distance, which controls the influence of observed data, is assumed as 5.0 km [7]. Kriging technique is employed for the residuals between the converted observed values at the base and the trend component. Simple Kriging is carried out assuming the residual distributions as a zero-mean Gaussian stochastic field. Adding the trend component to the obtained random component, the strong motion indices at the base are estimated. Multiplying the amplification factors to the obtained values at the base, the spatial distribution at the ground surface is finally obtained (Eq. (1) and (2)). The validity of this estimation method is discussed in Reference [7].

RELATIONSHIP BETWEEN SEISMIC INTENSITY AND REACTIONS OF DRIVERS

Distribution of Seismic Intensity along the Expressway

Figure 3 shows the estimated spatial distribution of JMA seismic intensity. To reveal the relationship between the seismic indices and the reactions of expressway drivers, the

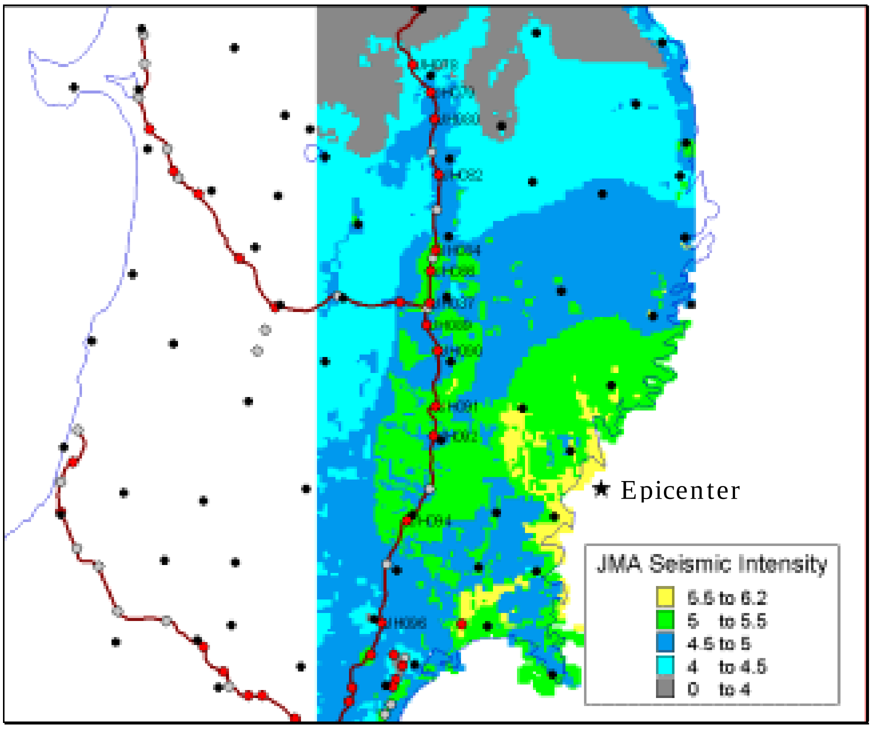


Figure 3. Estimated distribution of JMA seismic intensity on ground surface

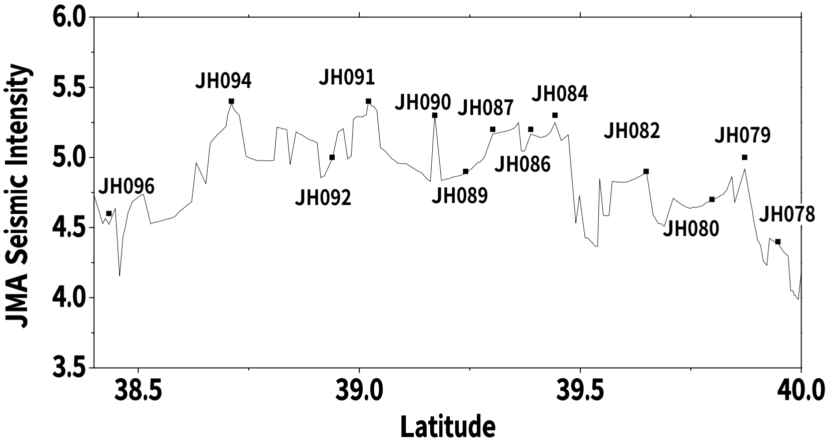
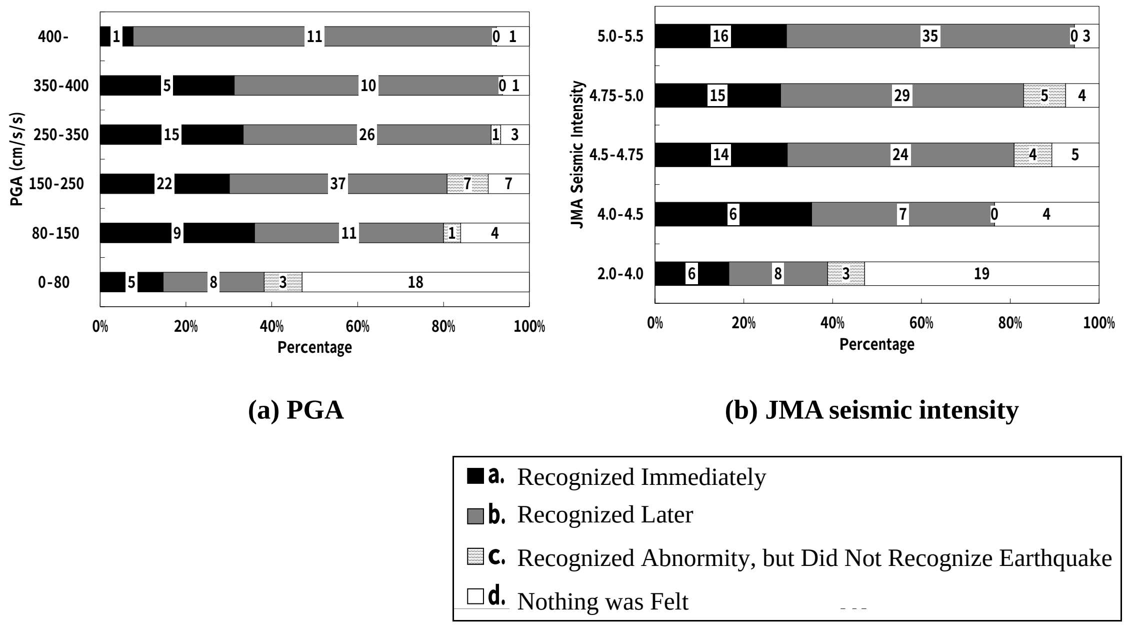


Figure 4. Estimated distribution of JMA seismic intensity along the expressway

distribution of seismic intensity along the expressway is necessary. The estimated seismic indices along the expressways are extracted as shown in Fig. 4. It should be noted that the spatial distribution is estimated in the entire Tohoku district, however, in Fig. 3 and Fig. 4, only a part of the obtained results is illustrated.



(a) PGA **(b) JMA seismic intensity**

Figure 5. Drivers' degree of recognition of earthquake occurrence

According to the questionnaire survey conducted by JH, the expressway section (between the adjacent interchanges) where the responders were driving during the earthquake can be detected. The seismic indices between the adjacent interchanges are calculated as the weighted average by Eq. (5).

$$\overline{X} = \sum x_i r_i \Big/ \sum r_i \tag{5}$$

where x_i is the estimated seismic index at a point on the expressway, and r_i is the representative length of x_i. $\overline{X}$ is the weighted average of the estimated seismic index.

Questionnaire Survey on Drivers' Reactions during Earthquake

JH has conducted the questionnaire survey for drivers in the 2003 Sanriku-Minami earthquake. In total, 206 answers were collected (ratio of respondents is 1 %). In the survey, the age of the responder, driver's license issued period, type of the vehicle, the driving section of the expressway when the earthquake occurred and so forth were requested to answer.

Relationship between Seismic Indices and Drivers' Responses

Figure 5 shows the relationship between the estimated PGA and the driver's degree of recognition of earthquake occurrence, and the relationship between the estimated JMA seismic intensity and the degree of recognition. As PGA and JMA seismic intensity become larger, more drivers recognized the earthquake occurrence. Only 40 % of drivers were aware of the earthquake in the areas where the JMA seismic intensity is smaller than 4.0. On the contrary, more than 80 % of drivers recognized the earthquake in the areas where the JMA seismic intensity is larger than or equal to 4.5.

Figure 6 shows the relationship between the type of the vehicle and the degree of earthquake recognition. Note that the results of the drivers in the area where the JMA seismic intensity is larger than or equal to 4.5 are shown in Fig. 6. As the size of the vehicle becomes larger, less drivers recognized the earthquake occurrence. It is considerd that the seismic motion affects the moving stability severely for a large-sized vehicle because the center of gravity is higher. However, the result was found to be opposite. Generally speaking, the vibration of an ordinary moving vehicle is large for large-sized vehicles, and hence, less drivers may distinguish the seismically induced vibrations. To draw a solid conclusion, more investigations are necessary in this viewpoint.

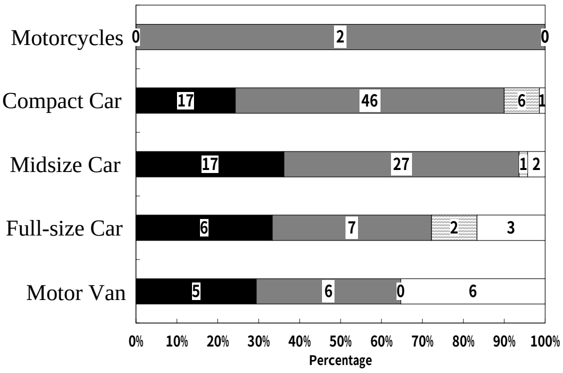


Figure 6. Relationship between the type of the vehicle and the degree of recognition of the earthquake in the area where the JMA seismic intensity is larger than 4.5 (The legend of the figure is the same as Fig. 5)

Figure 7 shows the reason why the driver recognized the earthquake occurrence with respect to the JMA seismic intensity. More than half of the respondents indicate the abnormal vibration of the vehicle as the reason for recognition. About 20 % of drivers felt the earthquake because the surrounding facilities, such as electric boards, and houses along the expressway were oscillating. The clear trend for the reason of recognition is not seen with respect to the JMA seismic intensity in the figure.

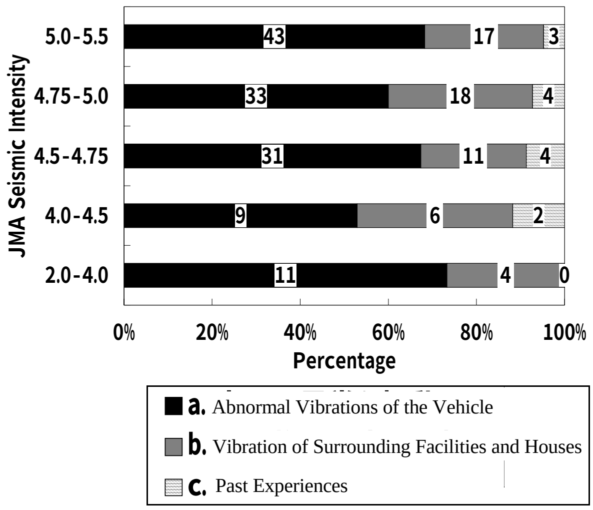


Figure 7. Reason why the earthquake occurrence was recognized

Figure 8 shows the relationship between the JMA seismic intensity and the behaviors of drivers after recognizing the earthquake. About 40 % of drivers in the area where the JMA seismic intensity is smaller than 4.0 kept on driving as usual even though they recognized the earthquake occurrence. As the JMA seismic intensity becomes larger, less drivers kept on going. Only 10 % of drivers kept on driving if the JMA seismic intensity was larger than or equal to 4.75. When the JMA seismic intensity is in the range of 4.5-4.75, 20% of drivers stopped the vehicle in the road shoulder. As the JMA seismic intensity becomes larger, that proportion becomes larger. As a whole, more than 50 % of drivers reduced the vehicle speed gradually, and some drivers stopped in the road shoulder when the JMA seismic intensity exceeds 4.0. It should be noted that three drivers stopped in their running lane after they recognized the earthquake.

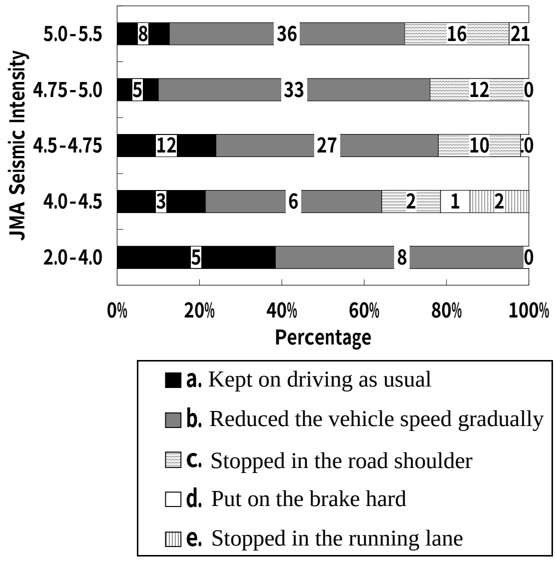


Figure 8. Relationship between the JMA seismic intensity and the responses of drivers after the recognition of earthquake

CONCLUSIONS

In this study, the relationship between the seismic intensity and the reactions of expressway drivers were investigated based on the questionnaire survey conducted by Japan Highway Public Corporation (JH) after the 2003 Sanriku-Minami earthquake.

The spatial distribution of seismic intensity was estimated using the seismic records at 132 K-NET stations and 52 JH stations which were deployed along the expressways. The results of the questionnaire survey were evaluated with respect to the estimated peak ground acceleration and the Japan Meteorological Agency (JMA) seismic intensity. Only 40 % of drivers were aware of the earthquake in the areas where the JMA seismic intensity is smaller than 4.0. On the contrary, more than 80 % of drivers recognized the earthquake in the areas where the JMA seismic intensity is larger than 4.0.

The abnormal vibration of the vehicle was indicated as the main reason for the recognition of the earthquake occurrence. This finding suggests that the strong ground motion will affect safe and stable driving. In this regard, it is important to reveal the effects of seismic motion to moving vehicles quantitatively. When the JMA seismic intensity is larger than or equal to 4.5, 20 % of drivers stopped in the road shoulder because they strongly felt the earthquake. If the traffic is heavy at the time of strong shaking, there may be difficulties in stopping safely in the road shoulder.

In this questionnaire survey, the relationship between the type of the vehicle and the effects of seismic motion is not so clear. The driving condition during an earthquake should be also considered for a further investigation. To draw a solid conclusion, it is necessary to accumulate this kind of questionnaire surveys.

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REFERENCES

1. Japan Automobile Federation website. "http://www.jaf.or.jp/data/carnum.htm" (in Japanese)
2. Yamazaki F. "Seismic monitoring and early damage assessment systems in Japan". Progress in Structural Engineering and Materials 2001; 3: 66-75.
3. Kawashima K, Sugita H, Kanoh T. "Effect of earthquake on driving of vehicle based on questionnaire survey". Structural Eng./Earthquake Eng., Japan Society of Civil Engineers 1989; 6:405-412.
4. Maruyama Y, Yamazaki F. "Fundamental study on the response characteristics of drivers during an earthquake based on driving simulator experiments". Earthquake Engineering and Structural Dynamics 2004; 33: 775-792.
5. Maruyama Y, Yamazaki F, Hamada T. "Microtremor measurements for the estimation of seismic motion along the expressways". Proceedings of 6th International Conference on Seismic Zonation 2000; 2:1361-1366.
6. Cressie N. "Statistics for spatial data". Wiley, 1993.
7. Yamazaki F, Motomura H, Hamada T. "Damage assessment of expressway networks in Japan based on seismic monitoring". Proceedings of 12th World Conference on Earthquake Engineering 2000; CD-ROM, 8p.
8. Shabeatari KT, Yamazaki F. "Attenuation Relation of Response Spectra in Japan Considering Site-Specific Term". Proceedings of 12th World Conference on Earthquake Engineering 2000; CD-ROM, 8p.
9. Yamazaki F, Wakamatsu K, Onishi J, Yamauchi H. "Relationship between Geomorphological Classification and Soil Amplification Ratio Based on JMA Strong Motion Records". Bulletin of ERS. Institute of Industrial Science, University of Tokyo, 1999; 32: 17-33.