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RELATIONSHIP BETWEEN SEISMIC INTENSITY AND DRIVERS' REACTION IN THE 2003 MIYAGIKEN-OKI EARTHQUAKE

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The relationship between the seismic intensity and the reactions of expressways drivers was investigated based on the questionnaire survey conducted by Japan Highway Public Corporation after the 2003 Miyagi-ken Oki earthquake. Only 40 % of drivers were aware of the earthquake in the areas where the Japan Meteorological Agency (JMA) seismic intensity was smaller than 4.0. On the contrary, more than 80 % of drivers recognized the earthquake in the areas where the JMA seismic intensity was larger than 4.0. 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 the safe and stable driving.

Key Words : *drivers' reactions, seismic motion, questionnaire survey, Simple Kriging, spatial distribution*

1. INTRODUCTION

The Japan Meteorological Agency (JMA) has revised the seismic intensity scale in 1996. They adopted the new instrumental seismic intensity scale[1)]. The JMA seismic intensity is widely used in Japan as an important index to show the sevearity of ground shaking and to be considered in emergency response just after an earthquake. According to the explanation table of the JMA seismic intensity scale (Feb., 1996), some people driving automobiles notice the tremor when the JMA seismic intensity scale reaches 4[1)]. It also says that many automobiles stop because it becomes difficult to drive when the JMA seismic intensity reaches 5+ (upper).

The number of automobiles in Japan is increasing year by year, and it is larger than 77 million including motorcycles[2)]. It is supposed that many people are driving just when a large earthquake occurs. As the demand for expressway traffic increases, safety requirements for expressways significantly increase even at the time of an earthquake. 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 present 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) has conducted the questionnaire survey to the drivers after the 2003 Miyagiken-Oki earthquake, which occurred on May 26, 2003 (JMA Magnitude is 7.0). To reveal the relationship between the seismic indices and the reactions of expressway drivers, the distribution of seismic intensity for the Miyagiken-Oki earthquake, is estimated based on Kriging technique[5)]. Then, the results of the questionnaire survey are compared with the estimated seismic intensity.

2. ESTIMATION OF THE DISTRIBUTION OF SEISMIC INDICES

Kriging technique[5], 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. 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*).

In order to obtain the spatial distribution of seismic intensity, it is necessary to remove the effect of local amplification of surface layers[6)-9)]. **Figure 1** shows the schematic figure for interpolation of strong motion indices performed in this study. The interpolation was carried out at the outcrop base as shown in **Fig. 1**. The amplification ratios[6)] estimated from the digital national land information of Japan, which are assigned for every 1×1 km mesh, are used except for the meshes where the K-NET seismic observation stations are located. For the meshes with K-NET seismic observations stations, the amplification ratios are estimated from the attenuation relationships constructed by Shabestari and Yamazaki[10)] (Eq. (1) and (2)).

$$\log_{10} ARA_i = c^A{}_i - c^A{}_0 \quad (1)$$

$$ARI_i = c^I{}_i - c^I{}_0 \quad (2)$$

where *ARA* and *ARI* are the amplification ratios for *PGA* and *I*, respectively. c_i is the station coefficient for K-NET stations. c_0 is the station coefficient for mountainous areas, which is used as the reference of amplification ratios[6)] ($c^A{}_0$=-0.107, $c^I{}_0$=-0.554). Then, the recorded seismic indices at the ground surface (PGA_{si} and I_{si}) are converted to those at the base by Eq. (3) and (4)

$$PGA_{bi} = PGA_{si} / ARA_i \quad (3)$$

$$I_{bi} = I_{si} - ARI_i \quad (4)$$

where PGA_{bi} and I_{bi} are the *PGA* and JMA seismic intensity at the outcrop base, respectively.

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

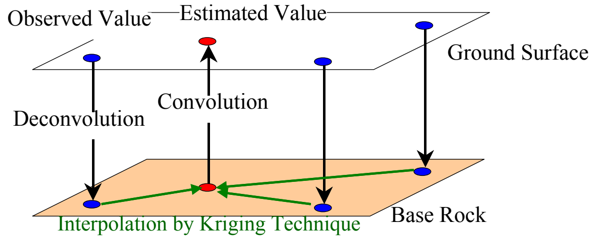


Fig.1 Schematic figure for interpolation of strong motion indices.

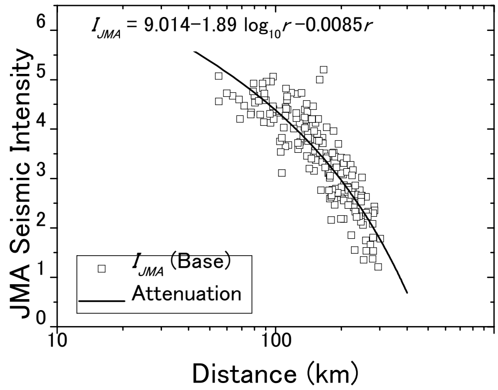


Fig. 2 Attenuation relationship of JMA seismic intensity at the base in the 2003 Miyagiken-Oki earthquake.

$$\log_{10} PGA = 4.768 - \log_{10} r - 0.0050r \quad (5)$$

$$I = 9.014 - 1.89 \log_{10} r - 0.0085r \quad (6)$$

where *r* is the shortest distance (km) to the fault rapture. **Figure 2** shows the attenuation relationship of JMA seismic intensity at the outcrop base.

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[11)]. 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 on the ground surface is finally obtained (Eq. (3) and (4)). The validity of this estimation method is discussed by Shabestari *et al*[11)].

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 distribution of seismic intensity along the expressway is necessary. The estimated seismic indices along the expressway 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 ob-

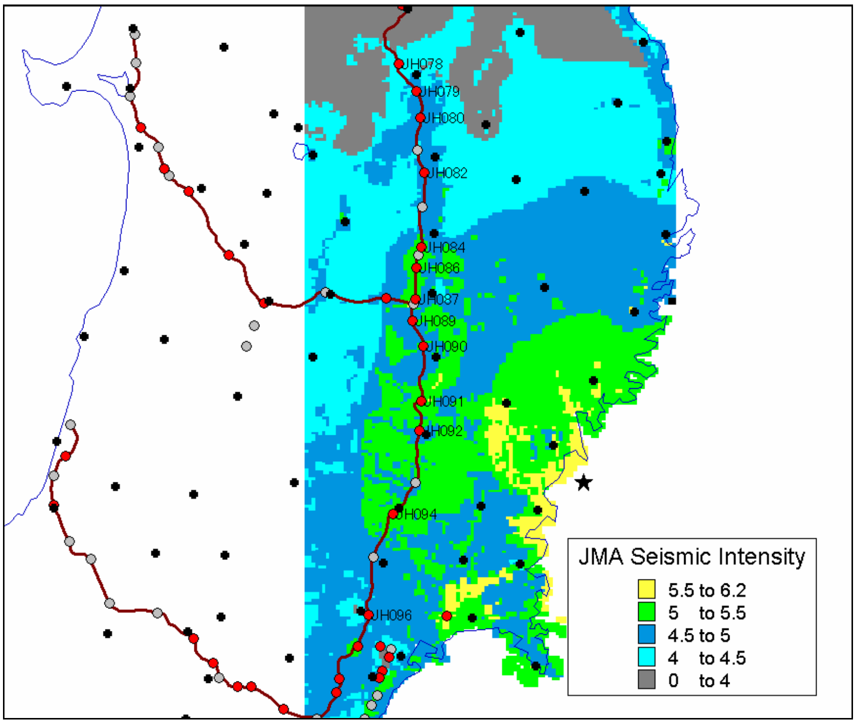


Fig. 3 Estimated distribution of JMA seismic intensity on ground surface

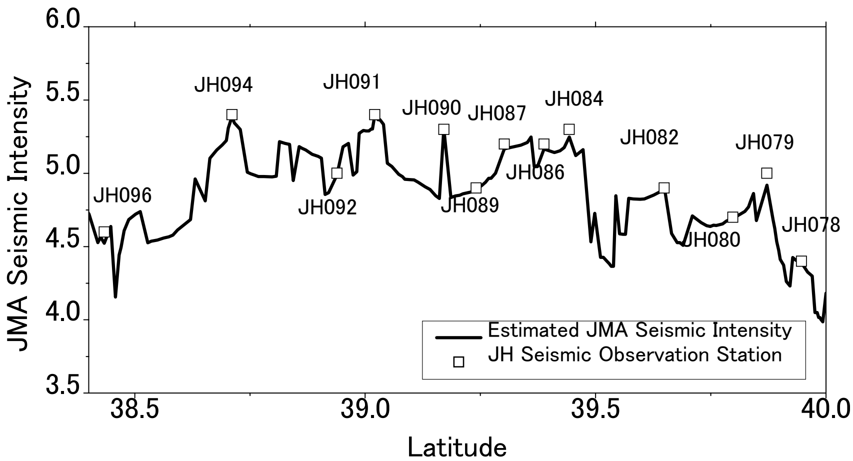


Fig. 4 Estimated distribution of JMA seismic intensity along the expressway

tained results is illustrated.

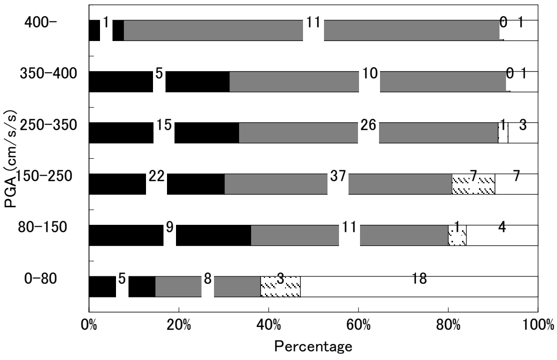
3. RELATIONSHIP BETWEEN SEISMIC INTENSITY AND REACTIONS OF DRIVERS

(1) Questionnaire survey on drivers' reactions during earthquake

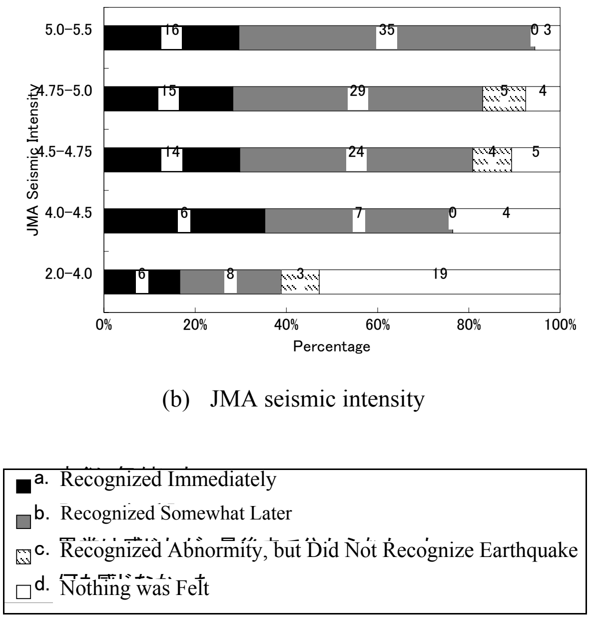
JH has conducted a questionnaire survey to the drivers after the 2003 Miyagiken-Oki earthquake. In total, 206 answers (195 males and 11 females) were collected (ratio of respondents is 1 %). In the survey, the age of the responder, driver's license issued period, type of the vehicle, the driving section of the expressway when the earthquake occurred and so forth were requested to answer. All the items of the questionnaire are shown in Appendix.

(2) Relationship between seismic intensity and earthquake recognition

Based on the result of the questionnaire survey, the relationship between the seismic intensity and the driver's recognition of earthquake occurrence is evaluated. According to the questionnaire survey, the expressway section (between the adjacent interchanges) where the responders were driving during the earthquake can be identified. The seismic indices between the adjacent interchanges are calculated as the weighted average by Eq. (7).



(a) PGA



(b) JMA seismic intensity

Fig. 5 Relationship between seismic intensity and degree of driver's recognition of the earthquake.

$$\bar{X} = \sum x_i r_i \Big/ \sum r_i \qquad (7)$$

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

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 became larger, more drivers recognized the earthquake occurrence. Only 40 % of drivers were aware of the earthquake in the areas where the JMA seismic intensity was smaller than 4.0. On the contrary, more than 80 % of drivers recognized the earthquake in the areas where the JMA seismic intensity was larger than or equal to 4.5. It should be noted that three drivers did not recognize the earthquake occurrence at all even though they were subjected to severe ground motion whose JMA seismic was in the range of 5.0-5.5.

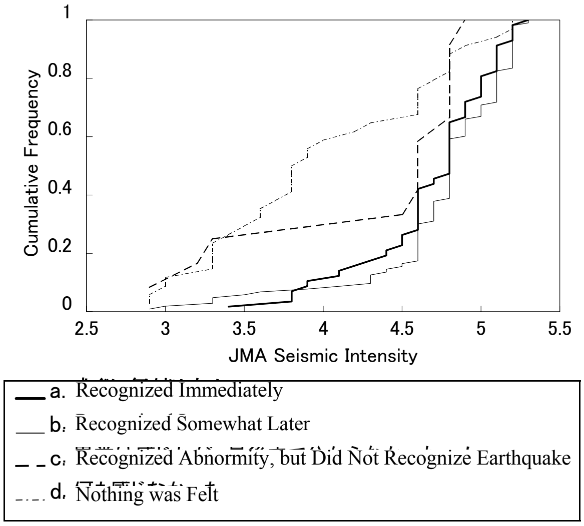


Fig. 6 Cumulative frequency of the degree of earthquake recognition with respsct to the JMA seismic intensity.

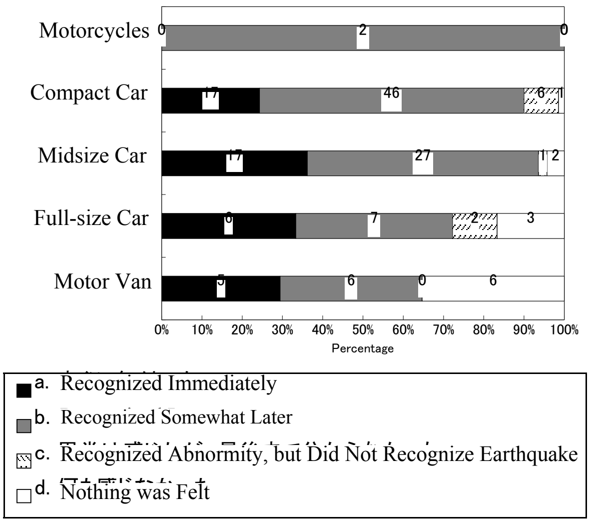


Fig. 7 Relationship between the type of the vehicle and the degree of recognition of the earthquake in the area where the JMA seismic intensity wss larger than

Figure 6 shows the cumulative frequency of the degree of earthquake recognition with respect to the JMA seismic intensity. It is observed that more drivers felt the earthquake occurrence if they were driving in the area where the JMA seismic intensity was larger than 4.5.

Figure 7 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 was larger than or equal to 4.5 are shown in the figure. As the size of the vehicle becomes large, less drivers recognized the earthquake occurrence. It is considered that the seismic motion affects the moving stability more for a large-sized vehicle because the center of gravity is

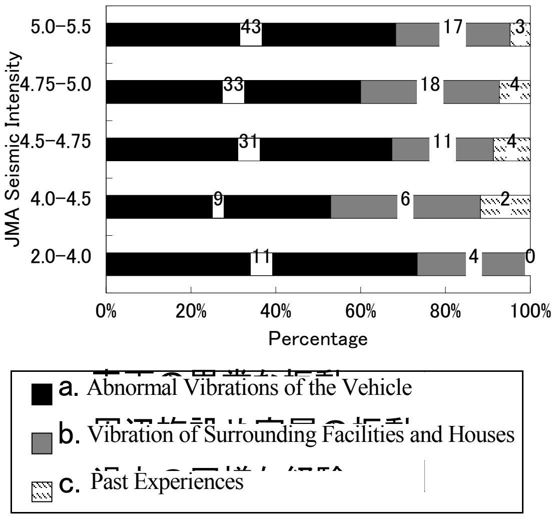


Fig. 8 Reason why the earthquake occurrence was recognized.

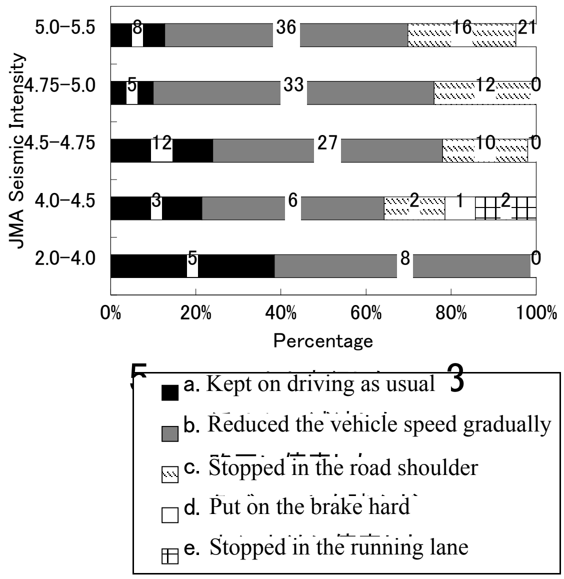


Fig. 9 Relationship between the JMA seismic intensity and the responses of drivers after the recognition of earthquake.

higher. However, the result was found to be opposite. Generally speaking, the ordinary vibration of a moving vehicle is large for large-sized vehicles, hence less drivers may recognize the seismically induced vibrations. To draw a solid conclusion, more investigations are necessary in this viewpoint.

Figure 8 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.

(3) Driver's response during an earthquake

Figure 9 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 was 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 was 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 exceeded 4.0. It should be noted that three drivers stopped in their running lane after they recognized the earthquake.

4. 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 Miyagiken-Oki 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 was smaller than 4.0. On the contrary, more than 80 % of drivers recognized the earthquake in the areas where the JMA seismic intensity was 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 was 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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APPENDIX ITEMS OF QUESTIONNAIRE

The items of the questionnaire are listed below:

I. Where were you driving just when the earthquake occurred?

II. Did you recognize the earthquake occurrence?
a. Recognized immediately
b. Recognized somewhat later
c. Recognized abnormity, but did not recognize earthquake
d. Nothing was felt

III. Why did you notice the earthquake?
a. Abnormal vibrations of the vehicle
b. Vibration of surrounding facilities and houses
c. Past experiences

IV. How did you responde after the earthquake?
a. Kept on driving as usual
b. Reduced the vehicle speed gradually
c. Stopped on the road shoulder
d. Put on the brake hard
e. Stopped in the running lane

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