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Validity of the Revised Questionnaire Seismic Intensity Method for the 2003 Tokachi-oki Earthquake

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Abstract

The validity of the revised questionnaire seismic intensity (RQSI) method is examined using data for the 2003 Tokachi-oki (Off Tokachi) earthquake. The new seismic intensity coefficient employed in the RQSI method was defined using data for the 1995 Hyogo-ken Nanbu (Kobe), 2000 Western Tottori Prefecture and 2001 Geiyo earthquakes, and is shown in this study to additionally provide a better correlation between the questionnaire-based and measured seismic intensities for the 2003 event compared to the previous methods. This result demonstrates that the RQSI method and new seismic intensity coefficient are valid for interplate earthquakes in addition to the intraplate and intraslab events on which it was defined.

Key-words : Questionnaire seismic intensity, Measured seismic intensity, Seismic intensity coefficient, The 2003 Tokachi-oki earthquake

1. Introduction

Information on seismic intensity is important in the planning of measures to mitigate future earthquake disasters. In 1979, Ohta *et al.* proposed a method for estimating the seismic intensity through a questionnaire survey (Ohta *et al.*, 1979). This questionnaire method has been widely used to evaluate several damaging earthquakes, and its reliability over the seismic intensity range of II to V has been confirmed with respect to the former Japan Meteorological Agency (JMA) intensity scale (since revised in 1996). However, this questionnaire-based method underestimated the seismic intensities of VI and VII of the JMA intensity scale for the 1995 Hyogo-ken Nanbu (Kobe) earthquake. Thus, the questionnaire method has been modified recently (Ohta *et al.*, 1998; Inoue *et al.*, 1999), and the results from these modified methods are now consistent with the JMA seismic intensity, although the seismic intensity coefficient between the measured seismic intensity and original questionnaire survey data has yet to be investigated.

The revised questionnaire seismic intensity (RQSI) method of Fukuzumi *et al.* (submitted, 2005) introduces a new seismic intensity coefficient that provides a better relationship between questionnaire survey data and measured seismic intensities. The coefficient was determined using data for the 1995 Hyogo-ken Nanbu (Kobe), 2000 Western Tottori Prefecture, and 2001 Geiyo earthquakes by a regression analysis of the relationships between the measured seismic intensities and the average "category number" reflecting the strength of earthquake motion (Table 1). Figure 1 shows an example of this relationship. The seismic intensity coefficient was thus determined from the measured seismic intensity corresponding to the average category number (Table 2). Categories with a poor correlation ($R < 0.6$) with measured seismic intensity were not assigned values.

In this study, the validity of the RQSI method is examined using questionnaire survey data obtained for the 2003 Tokachi-oki (Off Tokachi) earthquake, concentrating on the conformity in the high-intensity range of VI-VII in the former JMA intensity scale.

Table 1. Examples of categories on the questionnaire (originally in Japanese).

Q. Was there any damage to the building?		
Category number	1	None
	2	Fine cracks in plaster
	3	Small cracks in walls, fall of pieces of plaster
	4	Large and deep cracks
	5	Collapse

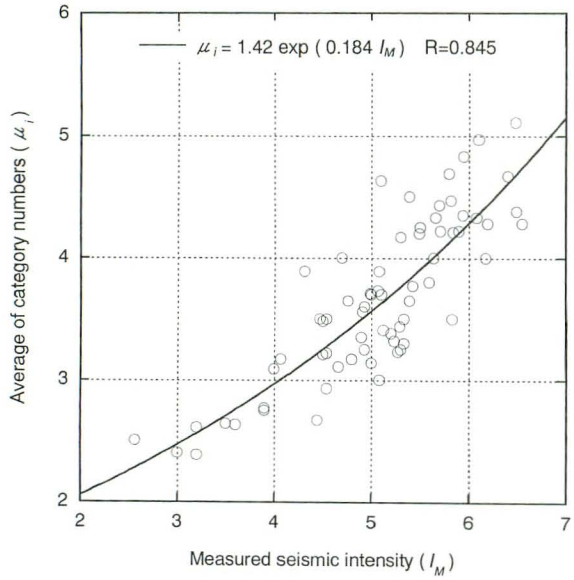

Fig. 1 Example of relationship between measured seismic intensity and average category number returned for each question.

2. Data

The questionnaire form designed by Ohta *et al.* (1979) was used in this study (English version, Ohta *et al.*, 1986) (Table 1). Each question presents 3 to 7 categories of effect, and a category number is assigned to each category. Questionnaire survey data obtained for the 2003 Tokachi-oki earthquake were collected by the Laboratory of Urban Disaster Protection Planning, Graduate School of Engineering, Hokkaido University and compiled by the present authors. The measured seismic intensity was compared directly with the average seismic intensity obtained from 4 or more questionnaire survey results within a 1.5 km radius of each seismic observation site. The observation sites are operated by JMA and K-NET for the National Research Institute for Earth Science and Disaster Prevention (NIED) (Fig. 2, Table 3).

Table 2. Newly determined seismic intensity coefficients for the RQSI method based on the relationship between measured and questionnaire-based seismic intensity.

		Category number						
		1	2	3	4	5	6	7
Question number	11			1.07	4.47	7.10		
	12			2.35	3.94	5.53	7.12	
	13		2.59	4.15	5.26	6.11	6.82	7.41
	14		2.89	4.25	5.62	6.98		
	15	3.20	4.10	5.00	5.90	6.80	7.70	
	16		1.86	4.06	5.63	6.84	7.83	
	17		3.64	4.61	5.57	6.53	7.49	8.45
	18							
	20	0.06	2.33	4.60	6.87	9.13		
	21	1.33	3.43	5.54	7.64	9.75		
	22	2.22	4.76	7.30	9.84	12.38		
	23							
	24							
	25		0.51	1.20	2.83	6.68		
	26							
	27							
	28							
	29							
	30	0.28	0.61	1.31	2.84	6.15		
	31		3.63	4.76	5.90	7.03	8.17	
	32		4.83	6.09	6.98			
	33		4.68	6.68				

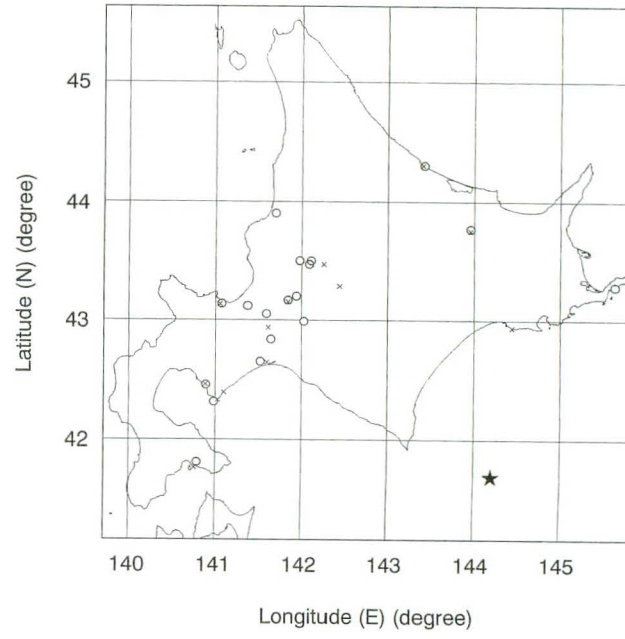

Fig. 2 Location of seismic observation sites used in this study. Open circle denote JMA sites, crosses denote K-NET sites, and the star indicates the epicenter of the 2003 Tokachi-oki earthquake.

Table 3. List of seismic observation sites used in this study.

Site name	Operated by	Measured seismic intensity
Hakodate	JMA	3.8
Hakodate	K-NET	3.9
Otaru	JMA	3.8
Otaru	K-NET	3.2
Muroran	JMA	3.4
Muroran	K-NET	4.6
Kushiro	K-NET	5.6
Kitami	JMA	4.8
Kitami	K-NET	4.3
Yubari	JMA	3.6
Iwamizawa	JMA	4.2
Iwamizawa	K-NET	4.4
Rumoi	JMA	2.6
Tomakomai	JMA	4.7
Tomakomai	K-NET	4.5
Ashibetsu	K-NET	3.2
Ebetsu	JMA	3.9
Akabira	JMA	3.1
Monbetsu	JMA	3.0
Monbetsu	K-NET	3.3
Mikasa	JMA	4.3
Nemuro	JMA	4.4
Takikawa	JMA	4.0
Utashinai	JMA	3.1
Furano	K-NET	3.9
Noboribetsu	K-NET	4.1
Eniwa	JMA	4.0
Date	JMA	3.9
Date	K-NET	4.0
Kitahiroshima	K-NET	4.2
Ishikari	JMA	4.4

3. Analysis and results

The questionnaire seismic intensity equation proposed by Ohta *et al.* (1979) is used to calculate the former JMA intensity from the questionnaire survey data. The seismic intensity from questionnaires (I_Q) is calculated for each reply to each question by

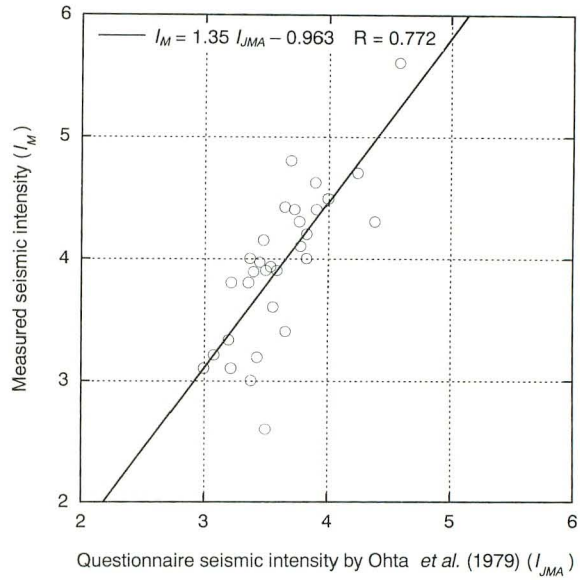

Fig. 3 Relationship between questionnaire-based and measured seismic intensity using the method of Ohta *et al.* (1979) for data from the 2003 Tokachi-oki earthquake.

$$I_Q = (\alpha Ne)^{-1} \sum_{i=1}^{Ne} \beta_i(m_i) \quad (1)$$

The JMA questionnaire-based seismic intensity (I_{JMA}) is then calculated from I_Q by

$$I_{JMA} = 2.958(I_Q - 1.456)^{0.567} \quad (2)$$

Here, α is a condition coefficient, Ne is the number of effective replies, m_i is the category number indicated in the ith question item, and $\beta_i(m_i)$ is the seismic intensity coefficient.

The RQSI method only requires calculation of equation (1), and does not involve a condition coefficient (α). Figure 3 shows the relationship between the averaged questionnaire results and measured seismic intensity using the method of Ohta *et al.* (1979) for questionnaire survey data obtained after the 2003 Tokachi-oki earthquake, Fig. 4 shows that for the modified method of Ohta *et al.* (1998), and Fig. 5 shows the relationship obtained using the RQSI method. Regression analysis of each of these three relationships yields the following equations:

$$I_M = 1.35 I_{JMA} - 0.963 \ (R = 0.772) \quad \text{(Ohta } et\ al.\text{, 1979)} \quad (3)$$

$$I_M = 1.25 I_{JMA} - 0.620 \ (R = 0.769) \quad \text{(Ohta } et\ al.\text{, 1998)} \quad (4)$$

$$I_M = 1.02 I_{JMA} - 0.0683 \ (R = 0.801) \quad \text{(RQSI)} \quad (5)$$

where I_M is the measured seismic intensity.

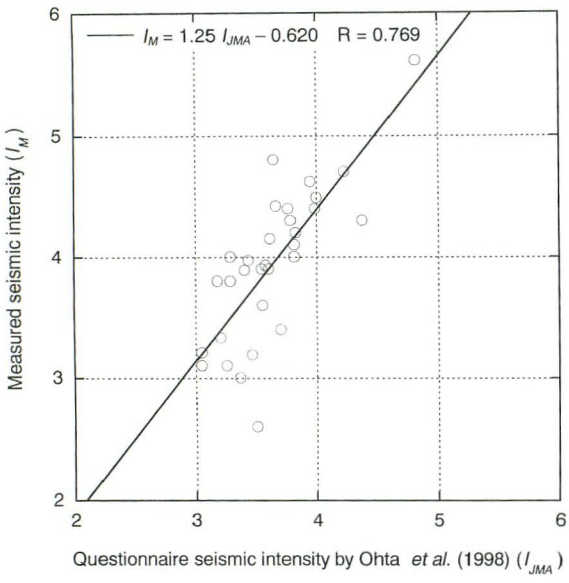

Fig. 4 Relationship between questionnaire-based and measured seismic intensity using the method of Ohta *et al.* (1998) for data from the 2003 Tokachi-oki earthquake.

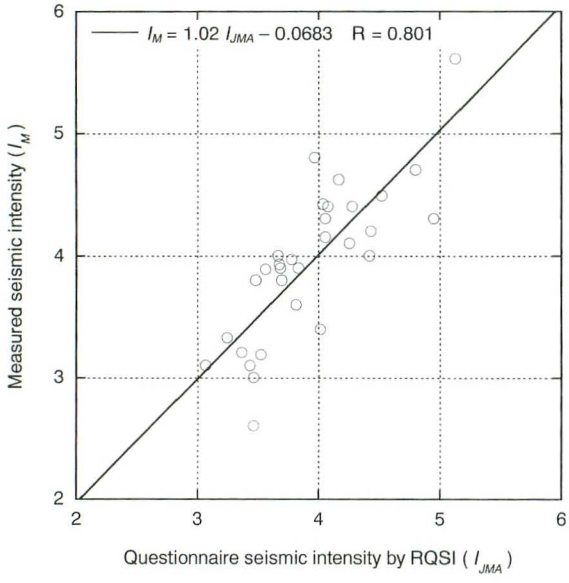

Fig. 5 Relationship between questionnaire-based and measured seismic intensity using the RQSI method of Fukuzumi *et al.* (submitted, 2005) for data from the 2003 Tokachi-oki earthquake.

4. Discussion

A high correlation was achieved between questionnaire survey data by the RQSI method and measured seismic intensity for the 1995 Hyogo-ken Nanbu (Kobe), 2000 Western Tottori Prefecture and 2001 Geiyo earthquakes. For the 2003 Tokachi-oki earthquake, the RQSI method also provides a better fit to the measured intensity than the previous questionnaire methods. The original and modified questionnaire-based seismic intensities tend to underestimate the intensity in the high-intensity range for the 2003 Tokachi-oki earthquake. Although there is only a small improvement in the correlation coefficient by the RQSI method, the slope of the line is much closer to unity (1.35 for Ohta *et al.* (1979), 1.02 for RQSI), indicating that the RQSI method provides a better fit.

These results demonstrate that the RQSI method, which was defined using data for the 1995 Hyogo-ken Nanbu (Kobe) and 2000 Western Tottori Prefecture earthquakes (both intraplate earthquakes) and the 2001 Geiyo earthquake (intraslab earthquake), is also applicable to the 2003 Tokachi-oki earthquake (interplate earthquake). Therefore, the re-determined seismic intensity coefficient of the RQSI method appears to be effective for not only intraplate and intraslab earthquakes but also interplate earthquakes.

Moreover, the seismic intensity coefficient by Ohta *et al.* (1979) obtained from the relationship between questionnaire and the former JMA seismic intensities. It is thought that the main difference of the seismic intensity coefficient between Ohta *et al.* (1979) and RQSI suggests the difference of the former JMA and measured seismic intensities.

5. Conclusion

The relationship between the measured seismic intensity and that determined by questionnaire survey using the RQSI method was examined using data for the 2003 Tokachi-oki earthquake. The RQSI was thus shown to provide a better correlation with the measured intensity compared to the previous questionnaire-based methods. It is therefore clear that re-determined seismic intensity coefficient of the RQSI method is valid for a range of earthquake types, including the interplate 2003 Tokachi-oki earthquake.

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