DAMAGE DETECTION OF EXPRESSWAYS IN THE 2004 NIIGATA-KEN CHUETSU EARTHQUAKE USING AERIAL PHOTOGRAPHS

Yoshihisa Maruyama, Fumio Yamazaki, Hiroyuki Yogai and Yoshiyuki Tsuchiya

ABSTRACT: In the Niigata-ken Chuetsu earthquake, which occurred on October 23, 2004, severe and minor damages were found in the expressway network. The expressways were closed or in traffic regulation because of the damages caused by this earthquake for about one month. In Japan, it is anticipated that the Tokai earthquake is coming and many severe damages are caused in various infrastructures. From this viewpoint, it is important to grasp the damages of expressways at an early stage just after the earthquake so as to make an efficient traffic control and a rapid disaster response. In this study, the relationship between the damage of expressways caused in the 2004 Niigata-ken Chuetsu earthquake and the seismic intensity was evaluated. The areas where the expressway suffered from many damages were subjected to severe ground motion whose JMA (Japan Meteorological Agency) seismic intensity was larger than 6.0. The major and minor damages of expressways can be detected using aerial photographs. It is also possible to detect some minor damages using high-resolution satellite images, e.g., QuickBird and IKONOS images. The remote sensing technology is expected to contribute for early damage detection just after the large earthquake.

KEYWORDS: aerial photographs; expressways; seismic intensity; damage detection

1. INTRODUCTION

In order to gather the earthquake information and to make an effective traffic control, the seismometer network is deployed along the expressways in Japan (Yamazaki and Motomura *et al.* 2000). The expressways are closed if the JMA (Japan Meteorological Agency) seismic intensity is larger than or equal to 4.5. In the Niigata-ken Chuetsu earthquake, which occurred on October 23, 2004, the expressways were closed just after the earthquake. Many major and minor damages were caused because of this earthquake. The traffic regulation was continued, and the expressway was tentatively re-opened on November 5. It took about a month to open the regular four-lane road.

The remotely sensed imagery data obtained from satellites and airborne platforms are effective to grasp damage distribution due to natural disasters (Yamazaki 2001). In the 2004 Niigata-ken Chuetsu earthquake, various organizations have investigated the possibility to grasp the damage distribution based on remote sensing technology. The platforms and sensors of remote sensing should be selected considering the area to cover, urgency, weather and time conditions, and the resolution of images. It is worth mentioning that QuickBird, a high-resolution commercial satellite with the maximum spatial resolution 0.6 m, has been launched on October 18, 2001 (DigitalGlobe website). These images can be used to detect damages of individual buildings after natural disasters (Kouchi *et al.* 2004; Yano *et al.* 2004). Airborne remote sensing is more suitable to collect the detailed damage distribution because aerial photographs have higher resolution than any other satellite images.

Combining the spatial distribution of seismic intensity with remote sensing technology is expected to realize the damage distribution of expressways at an early stage just after the earthquake. In this study, the relationship between seismic intensity and the number of damages caused in the expressway network is evaluated. In addition that, visual damage inspection was conducted using aerial photographs taken by Geographic Survey Institute, Japan. Based on the field photos taken by Central Nippon Expressway Co. Ltd., the degree of damages which can be detected by aerial photographs and other satellite images is discussed.

2. ESTIMATION OF THE SPATIAL DISTRIBUTION OF SEISMIC INTENSITY BASED ON KRIGING TECHNIQUE

In order to reveal the relationship between seismic intensity and the damage distribution of expressways, the spatial distribution of seismic intensities were obtained based on Kriging technique (Deutsch and Journel 1992). 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, 55 ground motion records at K-NET seismic observation stations (Kinoshita 1996), which were deployed by National Research Institute for Earth Science and Disaster Prevention, 2 ground motion records at JMA seismic observation stations (JMA Ojiya and JMA Kawaguchi), and 26 ground motions recorded at seismic observation stations deployed along the expressways are used for the estimation of the spatial distribution of the peak ground acceleration (*PGA*), peak ground velocity (*PGV*) and the JMA seismic intensity (*I*) (Karim and Yamazaki 2002).

In order to obtain the spatial distribution of seismic intensity, it is necessary to remove the effect of local amplification of surface layers. Figure 1(a) 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(a). The amplification ratios (Yamazaki and Wakamatsu *et al.* 2000) estimated from the digital national land information of Japan (Fig. 1(b)), 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 (2000) (Eq. (1) and (2)).

$$\log_{10} ARA_i = c^A{}_i - c^A{}_0 \tag{1}$$

$$\log_{10} ARV_i = c^V{}_i - c^V{}_0 \tag{2}$$

$$ARI_i = c^I{}_i - c^I{}_0 \tag{3}$$

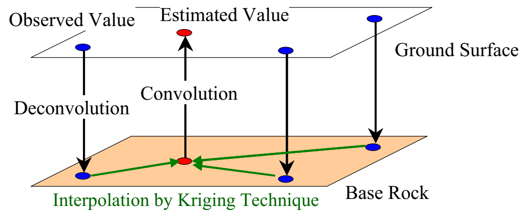
where *ARA*, *ARV* and *ARI* are the amplification ratios of *PGA*, *PGV* and *I*, respectively. c_i is the station coefficient for K-NET stations. c_0 is the station coefficient for mountainous areas, which is used as the reference of amplification ratios ($c^A{}_0$=-0.107, $c^I{}_0$=-0.554). Then,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

$$PGA_{bi} = PGA_{si} / ARA_i \tag{4}$$

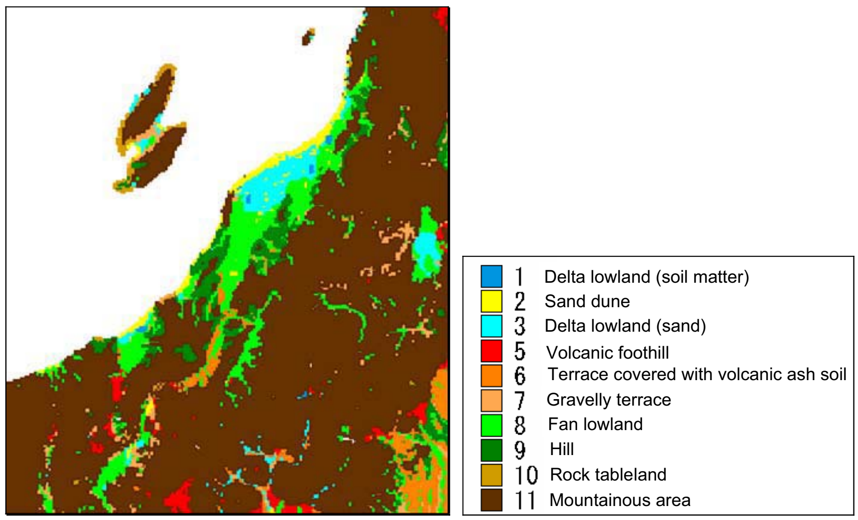
$$PGV_{bi} = PGV_{si} / ARV_i \tag{5}$$

$$I_{bi} = I_{si} - ARI_i \tag{6}$$

where PGA_{bi}, PGV_{bi} and I_{bi} are the *PGA*, *PGV*, and *I* at the outcrop base, respectively.



(a) Schematic Figure of Kriging Method



(b) Soil Classification based on the Digital National Land Information of Japan

Figure 1. Estimation Method of Distribution of Seismic Intensities and Soil Classification used in this Study

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

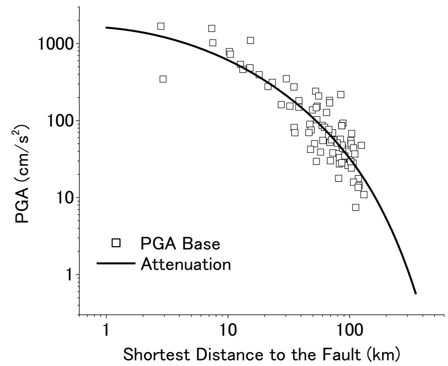
$$\log_{10} PGA = 4.026 - 0.00492r - \log_{10}(r + 5.5) \tag{7}$$

$$\log_{10} PGV = 2.610 - 0.00453r - \log_{10}(r + 0.6) \tag{8}$$

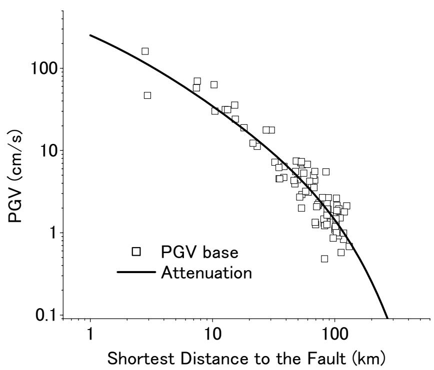
$$I = 7.532 - 0.01055r - 1.89\log_{10}(r + 1.1) \tag{9}$$

where r is the shortest distance (km) to the fault rapture. Figure 2 shows the attenuation relationships obtained in this study at the outcrop base.

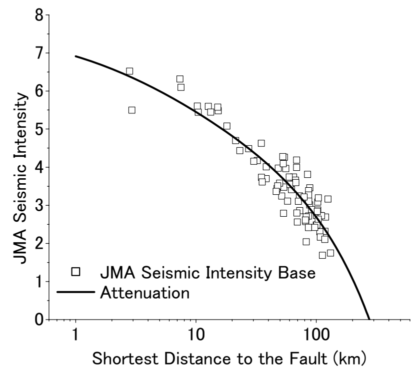
In the Kriging technique, a spatial auto-correlation function should be assigned. An exponential function is employed in this study. The correlation distance, which controls the influence of observed data, is assumed as 5.0 km (Shabestari *et al.* 2004). Kriging technique is employed for the residuals 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



(a) PGA



(b) PGV



(c) JMA Seismic Intensity

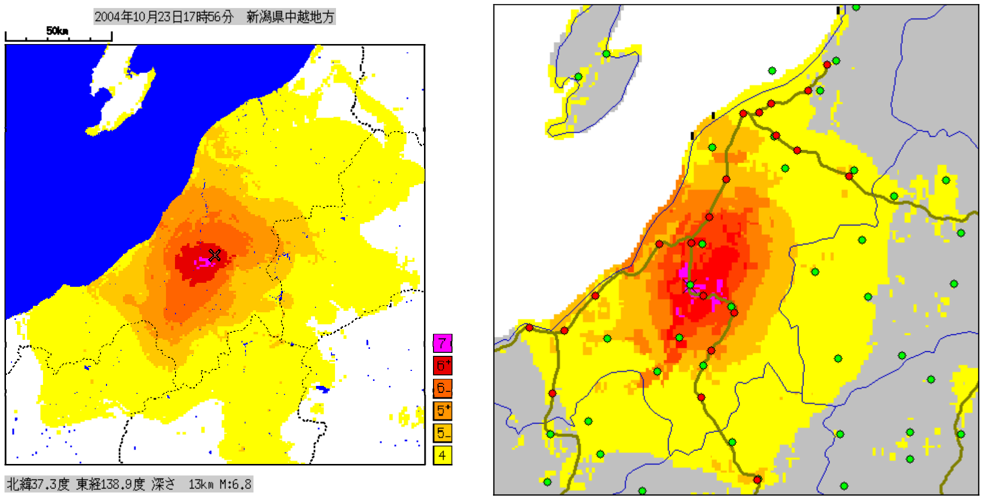
Figure 2. Attenuation Relationships of Seismic Indices at the Outcrop Base

distribution on the ground surface is finally obtained (Eq. (4), (5) and (6)). The validity of this estimation method is discussed by Shabestari *et al* (2004).

JMA provides the spatial distribution of JMA seismic intensity using the ground motion records from their seismometers. Figure 3 compares the spatial distribution of JMA seismic intensity provided by JMA with the one calculated by our method. The method and data employed to estimate the spatial distribution in this study are different from those employed by JMA. However, from both results, the areas subjected to severe ground motion whose JMA seismic intensity is in the range of 6 lower (6-) to 7 lie from the southwest to the northeast. Thus, the estimated distribution of JMA seismic intensity by us is considered to give similar level of accuracy with the one provided by JMA.

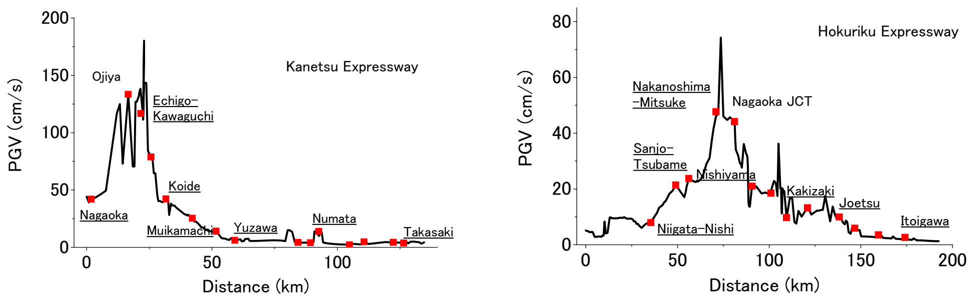
3. RELATIONSHIP BETWEEN THE DAMAGE DISTRIBUTION OF EXPRESSWAYS AND THE SEISMIC INTENSITY

3.1 Distribution of Seismic Intensity along the Expressways



(a) Presented by JMA **(b) This Study**

Figure 3. Comparison of the Spatial Distribution of JMA Seismic Intensity

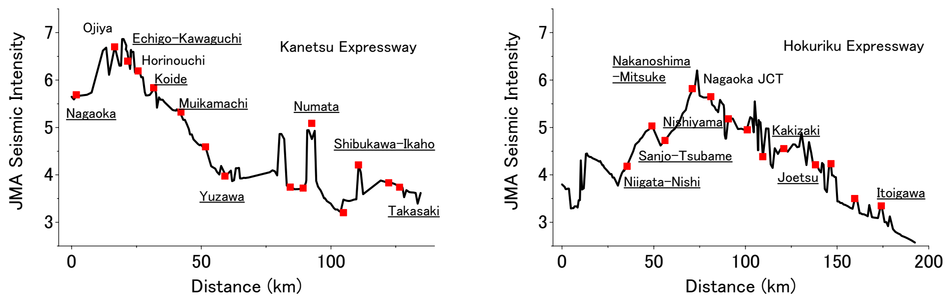


(a) Kanetsu Expressway **(b) Hokuriku Expressway**

Figure 4. Distribution of PGV along the Expressways

Based on the spatial distribution of seismic intensity, the seismic indices were extracted along the expressways. Figures 4 and 5 show the distribution of PGV and JMA seismic intensity along the expressways, respectively. According to the figure, the sections from Koide Interchange (IC) to Nagaoka IC in Kanetsu Expressway, and from Nagaoka Junction (JCT) to Nakanoshima-Mitsuke IC in Hokuriku Expressway were subjected to the ground motion whose JMA seismic intensity is larger than 6.0. In particular, the sections from Horinouchi IC to Nagaoka IC were suffered from severe ground motion whose JMA seismic intensity is larger than 6.5.

3.2 Relationship between the Number of Damages of the Expressway and Seismic Intensity



(a) Kanetsu Expressway **(b) Hokuriku Expressway**

Figure 5. Distribution of JMA seismic intensity along the Expressways

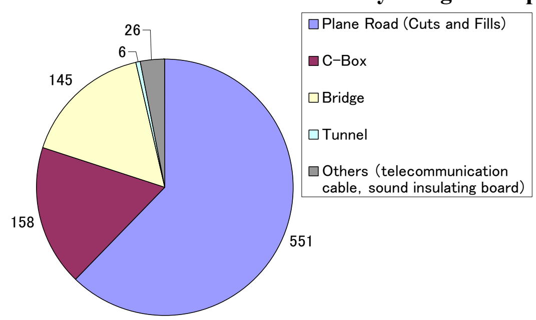


Figure 6. The Number of Damages of the Expressways in the 2004 Niigata-ken Chuetsu Earthquake

Figure 6 shows the number of damages of the expressways. More than 60 % of damages are associated with the plane roads, e.g. cuts and fills. Then, the number of damages of box culverts (C-Box) is about 20 %, and that of bridges is 15 %.

The relationship between the seismic intensity and the number of damages of the expressways is evaluated. The seismic intensity between adjacent interchanges is calculated as the weighted average (Eq. (10)).

$$\overline{X} = \sum x_i r_i \Big/ \sum r_i \tag{10}$$

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. $\overline{X}$ is the weighted average of the estimated seismic index.

Figures 7 and 8 show the relationship between the average PGV and the number of damages of the expressways, and the relationship between the average JMA seismic intensity and the number of damages, respectively. In these figures, the number of damages of the expressways is normalized by the length of the sections. According to the figures, the number of damages concentrates on the sections between Horinouchi IC and Echigo-Kawaguchi IC, and between Echigo-Kawaguchi IC and Ojiya IC in Kanetsu Expressway. The number of damages in Hokuriku Expressway is not larger than that in Kanetsu Expressway. All of the damages of the expressways are found in the sections whose average JMA seismic intensity is larger than 5.0. Most of them are associated with the sections whose average JMA seismic intensity is larger than 6.0.

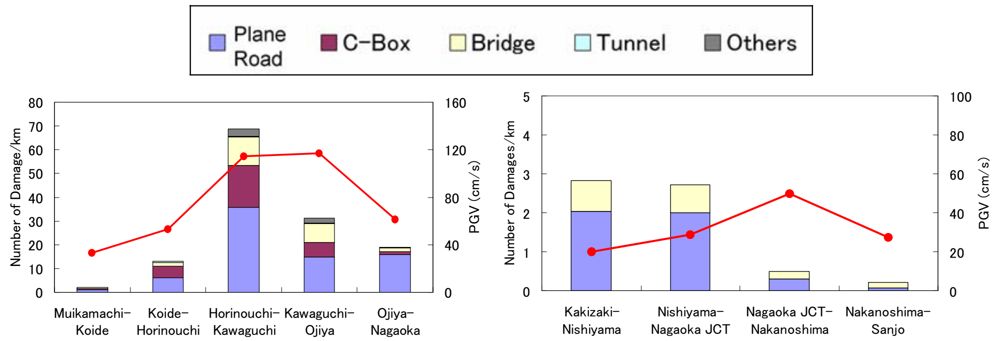


Figure 7. Relationship between the Average PGV and the Number of Damage of the Expressways

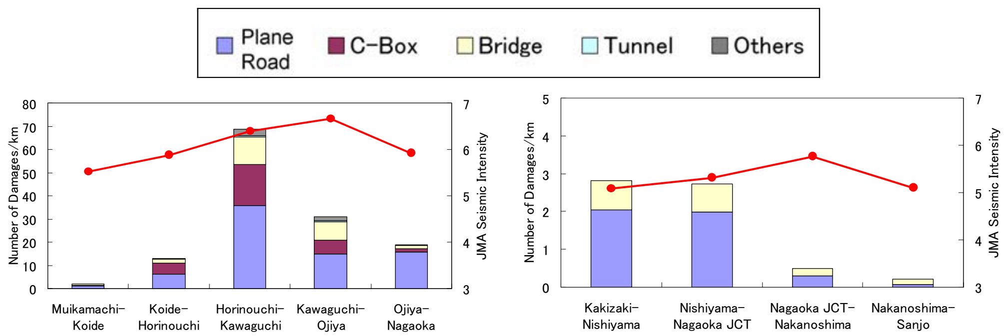


Figure 8. Relationship between the Average JMA Seismic Intensity and the Number of Damage of the Expressways

For a further research, it is important to investigate the relationship between the damage level and the seismic intensity. The empirical vulnerability functions can be obtained for various kinds of structures, and they will be compared with those of previous damaging earthquakes.

4. VISUAL DAMAGE INSPECTION OF EXPRESSWAYS USING AERIAL PHOTOGRAPHS

Utilization of satellite images and aerial photographs is effective to grasp the damage distribution due to natural disasters (Bitelli *et al.* 2004). The Geographic Survey Institute, Japan, has taken aerial photographs of heavily damaged areas on October 24 and 28, 2004. In some photographs, the expressways are captured. Therefore, it is possible to conduct the visual inspection and to compare the result of visual damage detection with that of the field investigation.

Figure 9 shows the aerial photograph which captures the expressway (between Horinouchi IC and Echigo-Kawaguchi IC). In this figure, the large-scale collapses of banks at 214.5kp (kilometer post), 215.1kp and 215.8kp are captured. These damages were easily interpreted from the aerial photograph. Some damages are also found from the figure where blue circles indicate. Figure 10 compares the damaged sections in the aerial photograph with those in the field photographs. The 20 cm gap of road surface can be identified from the aerial photo at 213.7kp. The gap of bridge joint was detected at 213.9kp. These damages are classified as severe damages. At 214.9kp, the depression of road shoulder with the length of 10 m was found, and it is reported that four sound insulating boards were fallen down. This depression of road shoulder is categorized as minor

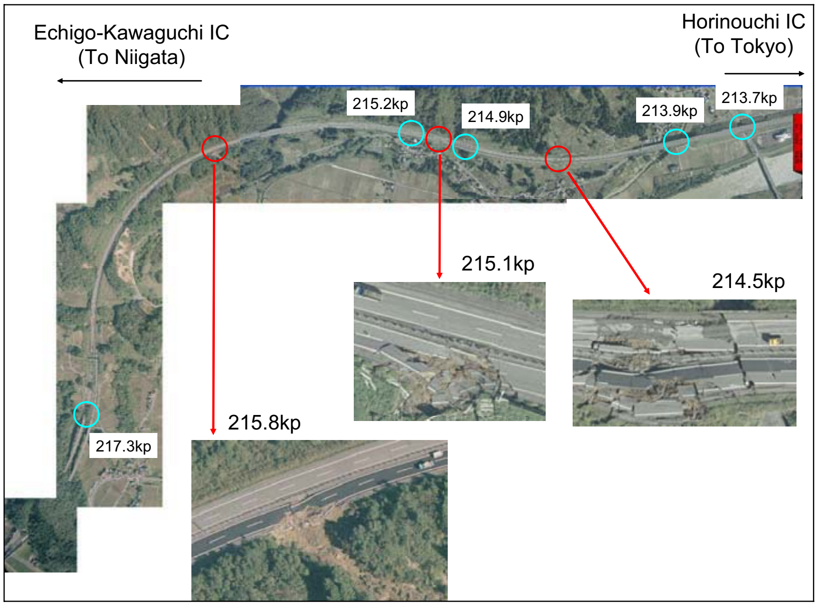


Figure 9. Aerial Photograph of Kanetsu Expressway between Horinouchi IC to Echigo-Kawaguchi IC

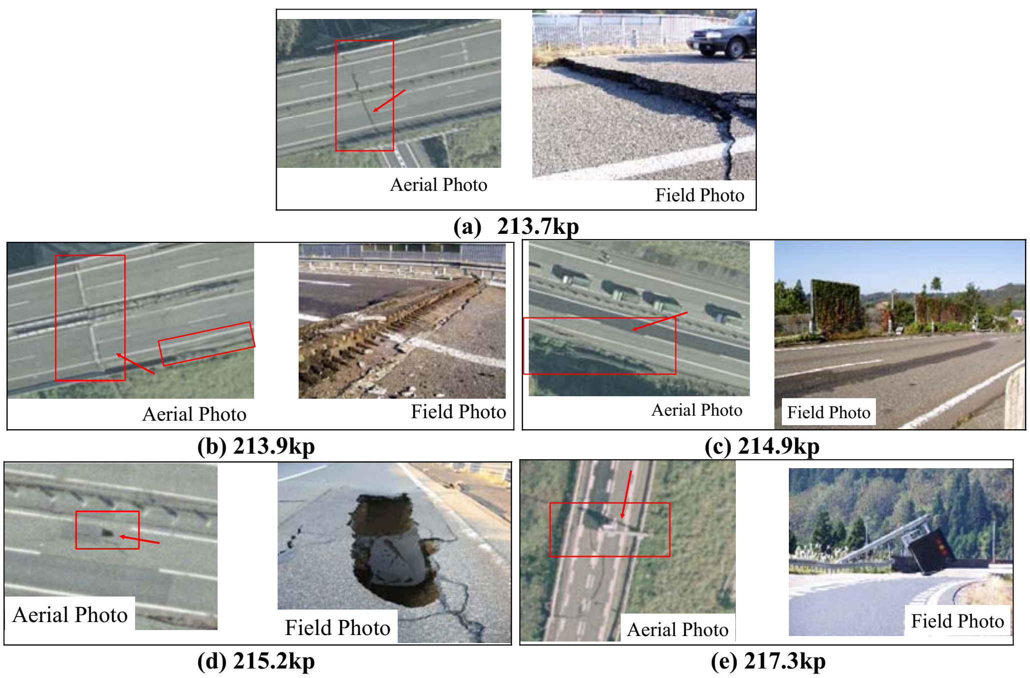
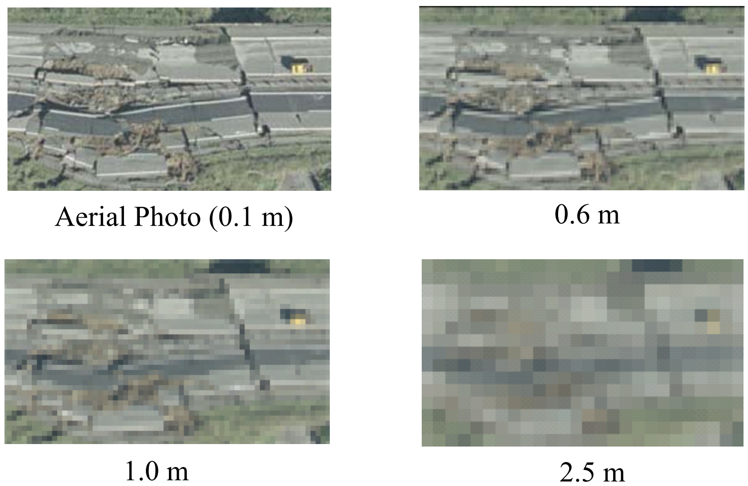


Figure 10. Comparison of Damages Detected from the Aerial Photograph with those from Field Photographs

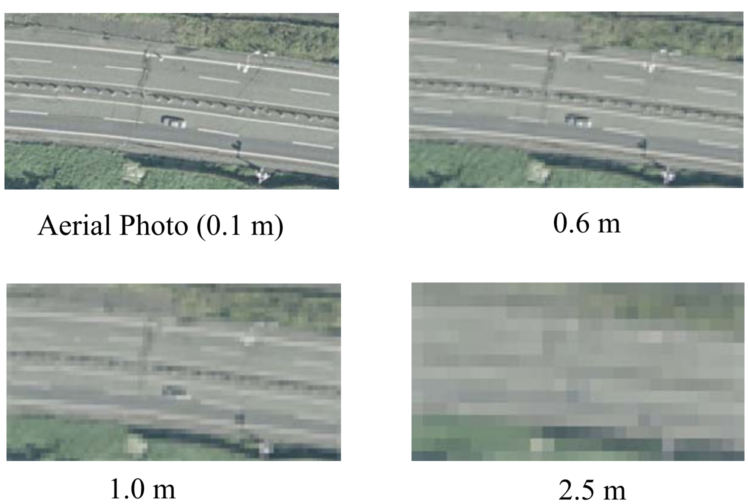
damage. The electric bulletin board was fallen down at 217.3kp, which can be identified from the aerial photograph.

Table 1. Resolutions of imageries taken from various satellites

Satellite	Spatial Resolution
QuickBird	0.6 m
IKONOS	1.0 m
SPOT-5	2.5 m



(a) 214.5 kp



(b) 215.2 kp

Figure 11. Comparison of images which captured the damaged sections of the expressway with various resolutions

Various platforms of remote sensing technology are available, and immediacy, coverage and resolution depend on the platforms. Table 1 shows the resolutions of imageries captured by some major high-resolution satellites. A high-resolution commercial satellite, QuickBird, was launched in 2001. QuickBird images have 0.6 m resolution (DigitalGlobe website). The IKONOS, which was launched in 1999, provide the image with the maximum resolution of 1.0 m (Space Imaging website). The SPOT-5 launched in 2002 can capture the image with the maximum resolution of 2.5 m and with the area of 3600 km^2 (Spot Image website).

The aerial photographs used in this study have the 0.1 m resolution. The resolution of aerial photo was changed into 0.6 m, 1.0 m and 2.5 m. These images correspond to those of satellites shown in Table 1 from the viewpoint of the resolution. Figure 11 shows the comparison of images which capture the damaged sections of Kanetsu Expressway. According to the figure, the large-sized collapse of bank at 214.5kp can be detected by all four images. The crack of road surface at 215.2kp can be identified by the images with the resolution of 0.6 m and 1.0 m, which correspond to the QuickBird image and IKONOS image. It is impossible to detect the crack from the image with the resolution of 2.5 m. The depression of road shoulder at 215.2kp is observed in the aerial photograph. It can be detected by the image with the resolution of 0.6 m, but it may be difficult to be detected by the 1.0 m resolution image.

Based on the investigation, the aerial photographs and the high-resolution satellite images, e.g. QuickBird images and IKONOS images, are effective to detect the damages due to earthquakes, which affect the availableness of expressways. It is expected that the damage distribution of expressways can be identified at an early stage by combining the spatial distribution of seismic intensity with the remote sensing technology.

5. CONCLUSIONS

As a fundamental study to grasp the damage distribution of the expressways just after an earthquake based on the spatial distribution of seismic intensity and remote sensing technology, the relationship between the damages of the expressways and the seismic intensity was investigated during the 2004 Niigata-ken Chuetsu earthquake. In addition that, visual inspection of damages was conducted using aerial photographs.

More than 60 % of damages of expressways were caused in the plane road, e.g., cuts and fills. The areas where the damages were caused by the earthquake were subjected to the ground motion whose JMA seismic intensity was larger than 5.0. Especially, most of them lay the sections between Horinouchi IC and Echigo-Kawaguchi IC, and between Echigo-Kawaguchi IC and Ojiya IC. These sections were subjected to the sever ground motion whose JMA seismic intensity was larger than 6.0.

According to the visual inspection of damages of the expressways performed in this study, large-sized collapses of banks were easily detected from the aerial photographs. Other cracks of road surface, gaps of bridge joint and depressions of road shoulder that affect the serviceability of expressways were also identified from aerial photographs. To investigate the capability of visual inspection using satellite images, the images with the resolution of 0.6 m, 1.0 m and 2.5 m were produced from the aerial photograph. As the result, the images with 1.0 m and 0.6 m resolutions, which are correspondence to IKONOS image and QuickBird image, may be helpful to grasp the damage distribution of expressways.

As a further study, it is important to investigate the relationship between the damage level and the seismic intensity. The empirical vulnerability functions can be obtained for various kinds of structures, and they will be compared with those from previous damaging earthquakes. In addition that, automated damage detection using aerial photographs will be performed and evaluate the damage level which can be identified using more detailed damage data.

REFERENCES

Bitelli, G., Camassi, R., Gusella, L. and Mongonl, A. (2004) Image Change Detection on Urban Area: The Earthquake Case. **Proceedings of International Society for Photogrammetry and Remote Sensing XXth Congress**, CD-ROM, No. 692, 6p.

Deutsch, C.V. and Journel, A.G. (1992) **Geostatistical Software Library and User's Guide**. Oxford University Press.

DigitalGlobe website. http://www.digitalglobe.com/

Karim, K. R. and Yamazaki, F. (2002) Correlation of JMA instrumental seismic intensity with strong motion parameters. **Earthquake Engineering and Structural Dynamics**, Vol. 31, 1191–1212.

Kinoshita, S. (1996) Kyoshin net (K-NET). **Seismological Research Letters**. Vol. 66, 841–844.

Kouchi, K., Yamazaki, F., Kohiyama, M., Matsuoka, M. and Muraoka, N. (2004) Damage Detection from QuickBird High-resolution Satellite Images for the 2003 Boumerdes, Algeria Earthquake. **Proceedings of the Asia Conference on Earthquake Engineering**, CD-ROM, 215-226.

Shabeatari, K.T. and Yamazaki, F. (2000) Attenuation Relation of Response Spectra in Japan Considering Site-Specific Term. **Proceedings of 12th World Conference on Earthquake Engineering**, CD-ROM, 8p.

Shabestari, K.T., Yamazaki, F., Saita, J. and Matsuoka, M. (2004) Estimation of the spatial distribution of ground motion parameters for two recent earthquakes in Japan. **Techtonophysics**, Vol. 390, 193-204.

Space Imaging website. http://www.spaceimaging.com/

Spot Image website. http://www.spotimage.fr/html/_167_.php

Yamazaki, F., Motomura, H. and Hamada, T. (2000) Damage Assessment of Expressway Networks in Japan based on Seismic Monitoring. **Proceedings of the 12th World Conference on Earthquake Engineering**, CD-ROM, 8p.

Yamazaki, F., Wakamatsu, K., Onishi, J. and Shabestari, K.T. (2000) Relationship between Geomorphological Land Classification and Site Amplification Ratio Based on

JMA Strong Motion Records. **Soil Dynamics and Earthquake Engineering**, Vol. 19, No. 1, 41-53.

Yamazaki, F. (2001) Applications of remote sensing and GIS for damage assessment. **Proceedings of the 8th International Conference on Structural Safety and Reliability**, CD-ROM, 12p.

Yano, Y., Yamazaki, F., Matsuoka, M. and Vu, T. T. (2004) Building Damage Detection of the 2003 Bam, Iran Earthquake Using QuickBird Images. **Proceedings of the 25th Asian Conference on Remote Sensing**, CD-ROM, 618-623.

ABOUT THE AUTHORS

Yoshihisa Maruyama is Research Associate at Department of Urban Environment Systems, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba, 263-8522, Japan. E-mail: ymaruyam@tu.chiba-u.ac.jp

Fumio Yamazaki is Professor at Department of Urban Environment Systems, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba, 263-8522, Japan. E-mail: yamazaki@tu.chiba-u.ac.jp

Hiroyuki Yogai is Director at Traffic and Environment Research Department, Expressway Research Institute, Central Nippon Expressway Co., Ltd. E-mail: h.yogai.aa@c-nexco.co.jp

Yoshiyuki Tsuchiya is Researcher at Traffic and Environment Research Department, Expressway Research Institute, Central Nippon Expressway Co., Ltd. E-mail: y.tsuchiya.aa@c-nexco.co.jp