RELATIONSHIP BETWEEN DAMAGE RATIO OF EXPRESSWAY EMBANKMENT AND SEISMIC INTENSITY IN THE 2004 MID-NIIGATA EARTHQUAKE

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ABSTRACT:

Many major and minor damages were found in the 2004 Mid-Niigata earthquake, especially for the embankments in Kanetsu Expressway and Hokuriku Expressway. The large-scale collapses of embankments were found in the areas where were subjected to severe ground motion. Using both the actual damage data and detailed spatial distribution of seismic intensity, this study conducts the statistical analysis on the relationship between the damage ratio of expressway embankment and seismic intensity to construct fragility curves. In order to obtain the spatial distribution of seismic intensity, simple kriging, a method of stochastic interpolation, was employed in this study. Based on the obtained results, major damages that affect the serviceability for traffic are found in the area where the peak ground velocity is larger than about 35 cm/s. The fragility curves constructed in this study may be helpful to predict the damage distribution in the expressway at an early stage of an earthquake so as to make an efficient traffic control and a rapid disaster response.

1 INTRODUCTION

In order to gather the earthquake information and to make an effective traffic control just after an earthquake, a seismometer network has been deployed along the expressways in Japan [Yamazaki et al., 2000]. The expressways are closed if the network shows JMA (Japan Meteorological Agency) seismic intensity is larger than or equal to 4.5. In the Mid-Niigata 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 carried out, and the expressway was tentatively re-opened on November 5. It took about a month to open the regular four-lane road.

The damages were mainly found in the embankment sections. Three large-scale collapses of expressway embankments were caused in the areas that were subjected to severe seismic motion [Maruyama et al., 2006]. In order to conduct a rapid disaster response and a proper traffic control just after an earthquake, it is important to estimate the damage probability in the expressway network at an early stage. Yamazaki et al. (2000) proposed fragility curves for bridge structures based on the damage data in the 1995 Kobe earthquake. However, the fragility curves for expressway embankment have not been constructed yet. The expressways consist of embankment sections in the rural areas in Japan.

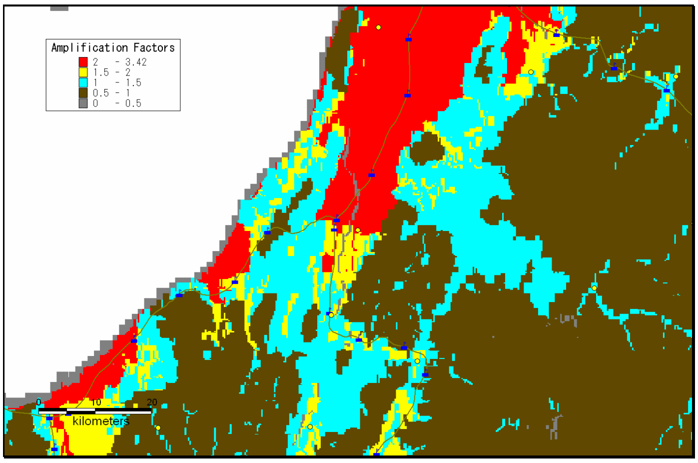


Figure 1. Amplification factors of the peak ground velocity in the Mid-Niigata region

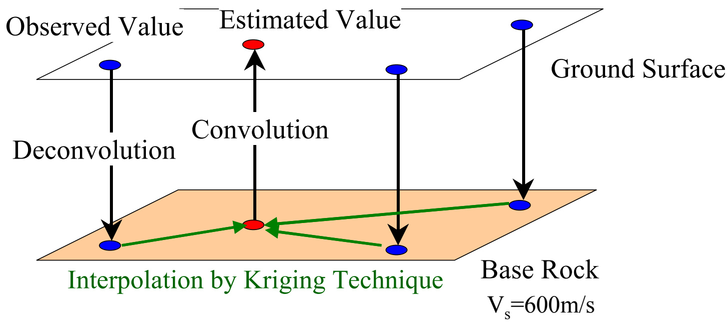


Figure 2. Schematic figure for interpolation of the peak ground velocity

Therefore, the fragility curves for expressway embankments are also desired to estimate damage distribution.

In this study, the fragility curves for expressway embankment were constructed based on the damage data in the 2004 Mid-Niigata earthquake. To achieve the objectives, the spatial distribution of the peak ground velocity (PGV) was estimated based on simple kriging [Cressie, 1993].

2 ESTIMATION OF PEAK GROUND VELOCITY IN THE MID-NIIGATA EARTHQUAKE

In order to evaluate the relationship between the seismic intensity and the expressway damages, the seismic intensity at the site where the damage was caused should be properly considered. Hence, the spatial distribution of the PGV was obtained in this study. Simple kriging, a method of stochastic interpolation, was employed to draw the spatial distribution. In kriging, 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 [Shabestari et al., 2004].

The effects of site conditions, which affect the magnitudes of strong motion records, should be eliminated to conduct the spatial interpolation of seismic indices. Wakamatsu et al. (2004) proposed the engineering geomorphologic map of Japan. This map consists of about 380,000 grid cells with the size of 1 x 1 km. The grid cells are categorized by geomorphologic characteristics into 19 classes. As for the Mid-Niigata region, the more detailed engineering geomorphologic map, which consists of grid cells with the seize of 250 x 250 m, is provided [Wakamatsu, 2006]. Matsuoka et al. (2006) draw the distribution of the average shear-wave velocity in the upper 30m (AVS30) throughout Japan using the engineering geomorphologic map. Fujimoto and Midorikawa (2006) constructed the relationship between the amplification factor of PGV and AVS30. In the relationship, the amplification factor is defined with respect to the outcrop base whose shear wave velocity (V_s) is equal to 600 m/s. Based on these results, the map of amplification factors of PGV, which consists of the 250 x 250 m sized grid cells, is obtained for the Mid-Niigata area (Fig. 1).

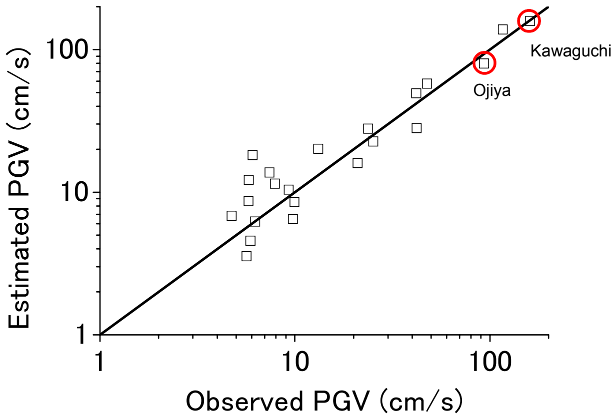


Figure 3. Comparison between the estimated peak ground velocity and the observed ones

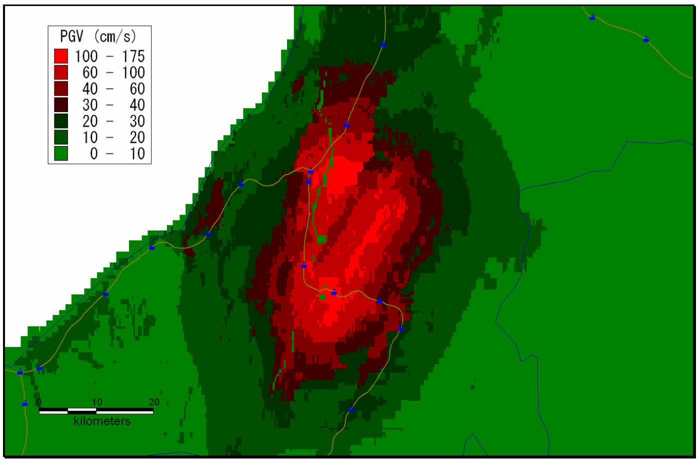


Figure 4. Estimated distribution of the peak ground velocity in the 2004 Mid-Niigata earthquake

Figure 2 shows the schematic figure for interpolation of the PGV performed in this study. First, the recorded PGV is deconvoluted to the outcrop base. Then, the interpolation is carried out at the base as shown in Fig. 2. Using the PGV at the outcrop base, the relationship is constructed. The attenuation relationship is used as a trend component in kriging. Lastly, the interpolated values are convoluted to the ground surface.

In order to evaluate the accuracy of estimation, the recorded PGV at K-NET accelerometers [NIED, 2007] were employed for kriging. Then, the estimated PGV at the site where the seismometer is installed along the expressway was compared with the recorded one (Fig. 3). In the 2004 Mid-Niigata earthquake, strong ground motions were recorded near the epicenter by JMA. The estimated PGV at the two stations (JMA Ojiya and JMA Kawaguchi) were also compared with the observed ones in Fig. 3. According to the figure, the estimated PGV shows good accuracy when the PGV is larger than 20.0 cm/s. It should be noted that the amplification factor at a K-NET accelerometer was determined using the station coefficient, c, proposed by Shabestari and Yamazaki (1999) and the relationship between the average shear wave velocity and the station coefficient constructed by Tamura et al. (2000). Based on these results, the amplification factor at K-NET station with respect to the outcrop base whose shear wave velocity is equal to 600 m/s can be described as $10^{c+0.23}$.

To evaluate the relationship between the expressway damage and seismic intensity, more accurate distribution of PGV along the expressways is needed. Hence, the seismic motion records at expressways were also considered in kriging. Because the station coefficients for the expressway accelerometers are not available for this study, the amplification factors shown in Figure 1 were used for kriging. Figure 4 shows the distribution of PGV in the 2004 Mid-Niigata earthquake. Because the seismometers are deployed at the interchanges of expressway, it is expected that the estimated

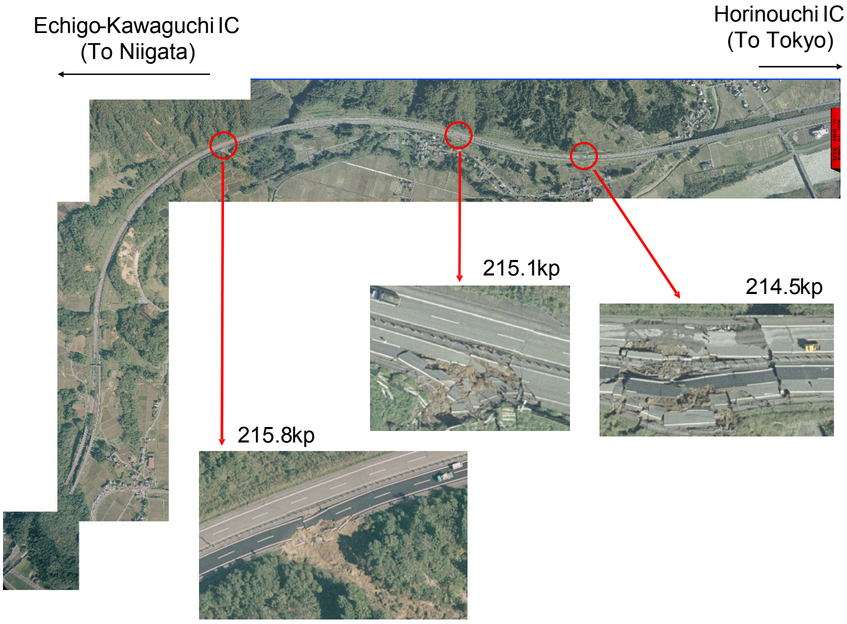


Figure 5. Post-earthquake aerial photograph of the Kanetsu Expressway showing severe damage at kilometre posts 215.8, 215.1, and 214.5

distribution of PGV shows good accuracy, especially along the expressways. Therefore, the distribution shown in Fig. 4 is used for the investigation in the next chapter.

3 RELATIONSHIP BETWEEN DAMAGE OF EXPRESSWAY EMBANKMENT AND PEAK GROUND VELOCITY

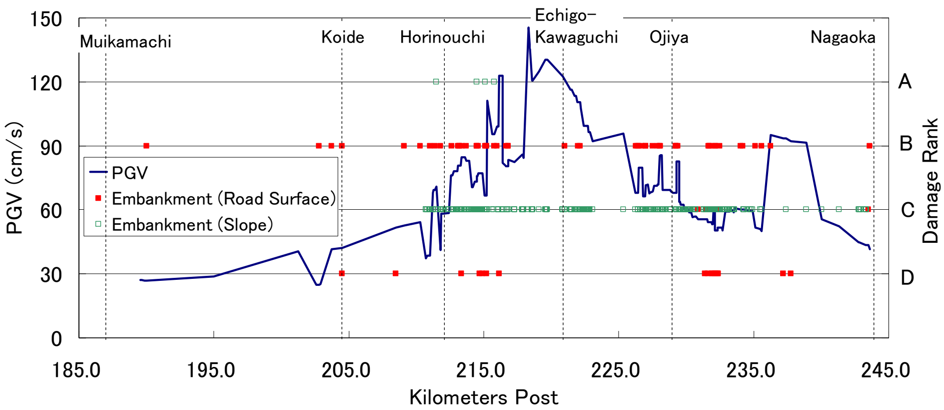
Major and minor damages were found in Kanetsu Expressway and Hokuriku Expressway, which extend near the epicenter of the 2004 Mid-Niigata earthquake. Figure 5 shows severe damage along a section of the Kanetsu Expressway. In this figure, the large-scale collapses of embankments at 214.5kp (kilometre post), 215.1kp and 215.8kp are captured. The damages were mainly found at the embankment sections. Hence, the relationship between seismic intensity and damage of embankment was evaluated using both the distribution of the PGV in the previous chapter and the actual damage data in the Mid-Niigata earthquake complied by Japan Highway Public Corporation (JH). Each damage is pointed at every 10 m along the expressway and the severity of damage is also denoted as the damage rank by JH. The damage rank is classified into four levels, i.e. A (large damage), B (moderate damage), C (small damage) and D (minor damage). The damages associated with damage ranks A and B are severe enough to disturb an ordinary traffic on the expressway.

Figure 6 shows the relationship between the PGV and damages of expressway embankment. The symbols of embankment damages are marked with respect to the damage rank. In Kanetsu Expressway, the damages associated with rank B are mainly located between Horinouchi interchange (IC) and Ojiya IC. Three large-scale collapses of embankment shown in Fig. 5 are classified as damage rank A in Fig. 6(a). In Hokuriku Expressway, severe damages (damage ranks A and B) were caused near Nagaoka junction (JCT). Almost all damages associated with damage ranks A and B were found in the area where the PGV was larger than 30.0 cm/s except for some damages.

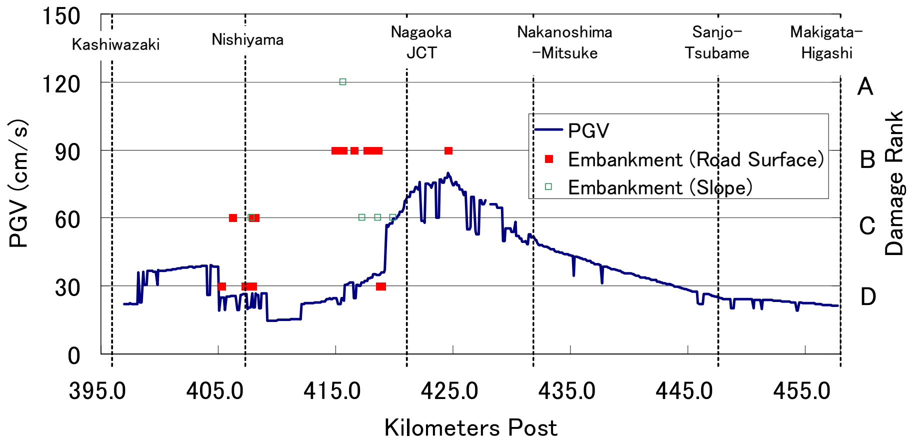
Based on the results, the fragility curves for expressway embankment are constructed. These fragility curves are expected to contribute for a countermeasure against an earthquake of expressway authorities and damage estimation just after an earthquake.

To construct fragility curves, the damage ratio of expressway embankment, P, is assumed to follow the Eq. (1).

$$P = C\Phi\left(\left(\ln PGV - \lambda\right)/\zeta\right) \quad (1)$$



(a) Kanetsu Expressway



(b) Hokuriku Expressway

Figure 6. Relationship between the peak ground velocity and damages of expressway embankment

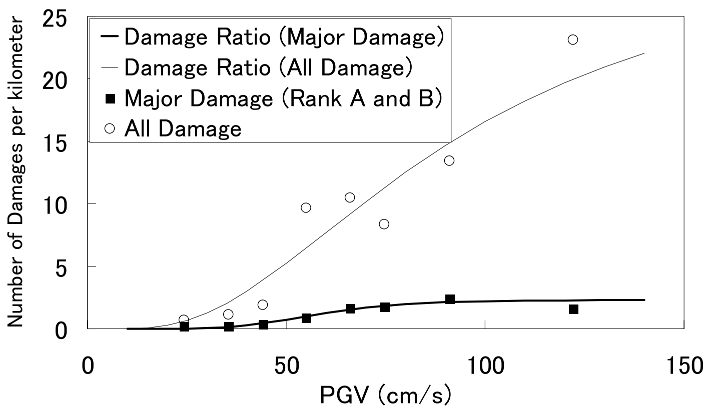


Figure 7. Fragility curves for expressway embankment with respect to the peak ground velocity

where $\Phi(x)$ is the standard normal distribution. λ, ζ and C are the constants determined by regression analysis. The damage ratio was calculated as a ratio between the number of damages and the length of expressway embankment sections.

The three parameters in Eq. (1) were determined by a weighted least squares method. The length of embankment section was used as a weighted factor in the regression process. Non-linear regression analysis was performed based on the quasi-Newton method.

Figure 7 shows the fragility curves of expressway embankment constructed in this study. According to the figure, the major damages (damage ranks A and B) may be caused when the PGV is larger than about 35.0 cm/s, and the maximum number of damages per kilometre is about 2.3. When the PGV is larger than about 20.0 cm/s, there may occur some minor damages.

4 CONCLUSIONS

In this study, the fragility curves of expressway embankment were constructed using the actual damage data of expressways in the 2004 Mid-Niigata earthquake. To achieve the objectives, the detailed distribution of peak ground velocity was estimated based on simple kriging.

According to the fragility curves, major damages that disturb an ordinary traffic on the expressway may be caused when the PGV is larger than about 35.0 cm/s. The fragility curves are expected to contribute for a countermeasure against an earthquake by expressway authority and damage estimation just after an earthquake.

The fragility curves proposed in this study were constructed based on the damage data in the Mid-Niigata earthquake. A further study may be necessary to discuss the applicability to other earthquake events.

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