An Attempt on the Fragility Curves for Expressway Embankments Considering the Difference in Various Conditions

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SUMMARY
It is important for the earthquake risk management to evaluate the level of possible damage to infrastructure in future earthquakes. For this purpose, fragility curve is a quite effective approach. However, with the limited experiences in the damage, it is difficult to propose various fragility curves which can consider the differences in the conditions of the structures. For example, it is impossible to evaluate the effect of seismic retrofit without preparing the fragility curves of the structure for before and after the improvement.

In this study, based on the damage case history in Mid Niigata Prefecture Earthquake in 2004, an approach to propose the fragility curves considering the differences in various conditions for the expressway is discussed. The damage of the embankment in the Kan-etsu and Hokuriku Expressway in the earthquake was classified with its structural condition. Especially, the damage to the embankment with a particular shape and close to culverts or bridges was listed up. With the list of damage, the relationship between the seismic ground motion level and damage ratio was summarized. Thus, the fragility curves for expressway embankments in various conditions can be discussed from the research results.

Keywords: Fragility curve, Expressway embankment, Slope failure

1. INTRODUCTION

It is important for the earthquake risk management to evaluate the level of possible damage to infrastructure in future earthquakes. For this purpose, fragility curve is a quite effective approach. For example, Maruyama et al. (2010), proposed a set of fragility curves for highway embankments based on damage case history and seismic intensity evaluation along the expressway[1)]. However, with the limited experiences in the damage, it is difficult to propose various fragility curves which can consider the differences in the conditions of the structures. For example, it is impossible to evaluate the effect of seismic retrofit without preparing the fragility curves of the structure for before and after the improvement.

In this study, based on the damage case history in Mid Niigata Prefecture Earthquake in 2004, an approach to propose the fragility curves considering the differences in various conditions for the expressway is discussed. The damage of the embankment in the Kan-etsu and Hokuriku Expressway in the earthquake was classified with its structural condition. Especially, the damage to the embankment with a particular shape and close to culverts or bridges was listed up. With the list of damage, the relationship between the seismic ground motion level and damage ratio was summarized.

2. EVALUATION OF NUMBAR OF DAMAGES BASED ON CASE HISTORIES

2.1. Classification of the damage based on the condition of the embankment

In this research, the damage case histories of Kan-etsu Expressway (Nagaoka I.C. to Muikamachi I.C.) and Hokuriku Expressway (Kashiwazaki I.C. to Makigata-higashi I.C.) in the Mid Niigata Earthquake in 2004 were used. These case histories are same with the data used in the proposal of Maruyama et al (2010). The damage level were classified 4 categories, A to D. Following the approach of Maruyama et al., fragility curves for more than B level damage and for more than D level damage were discussed in this study. Here, the damage level more than B corresponds to the difficulties of traffic, and the damage level more than D corresponds to the all kind of minor damage including gaps less than 1 cm.

Considering the fact that gap tends to occur at the location of bridges or culvert, the observed damage was classified by the condition of the embankment. In this area, most of the embankments were constructed on flat rice field, and it has similar height and shape. Then, the embankments which have irregular shape were excluded at the first step. The remained embankments have a similar shape shown in Figure 1. The height of the typical embankment is 5 m, having a symmetric shape. It might be constructed on rice field. There could be some kinds of ground improvement for the foundation, but the details are out of scope of this study so far.

The expressway with this typical shape of embankment was classified into 3 categories. One is the area within 50 m from a bridge, and another is the area within 50 m from a culvert. This is because the existence of a structure (bridge or culvert) may cause damage to the embankment easily. Note there was no tunnel around the typical shape of embankment chosen in this study. There is no clear reason to choose 50 m as the distance where the effect of structure appears. The accuracy of the reported damage is 10 m. The used distance of 50 m might be larger than the distance of possible real phenomenon. The remaining area is the embankment where no effect of structure applied, and categorized as the normal condition.

The index for the seismic intensity in this study is PGV (cm/s) at the ground surface. This is because Maruyama et al. (2010) already estimated the distribution of this index value for this area[1)]. Figure 2 shows the distribution of the PGV along the expressway. Note the PGV values at Ojiya I.C. and Horinouchi I.C. where strong motions were not recorded were corrected from the estimation used in Maruyama et al. This correction was done by an application of the recent strong motion estimation method considering the site amplification characteristics and phase effect. Since new PGV values at Ojiya I.C. and Horinouchi I.C. were used, PGV values at other locations along the expressway where Kriging method was applied for the estimation were also corrected.

Table 3 is the summary of number of damage in each PGV level. The problem of the approach used here is how to count the number of damage. Sometimes, more than 2 damage data were reported at the same point. In other word, number is not related to the scale of damage in this data. This is the task to be considered in future studies.

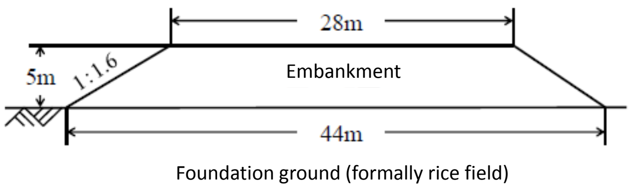
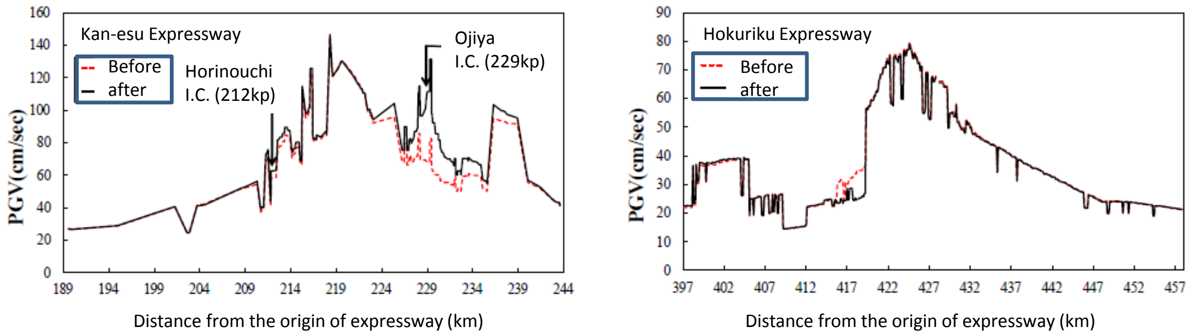


Figure 1. The typical cross section of embankment considered in this study



(a) Kan-etsu Expressway (b) Hokuriku Expressway

Figure 2. Estimated PGV distribution along the Expressway
(before and after the correction for Ojiya I.C. and Horinouchi I.C.)

Table 1. Number of damage in PGV level and embankment category

(a) Close to a culvert

PGV [cm/sec]	A	B	C	D	Total length [km]
~30	0	4	2	1	103
30~40	0	0	0	0	65
40~50	0	0	0	0	38
50~60	0	2	4	0	34
60~70	0	5	23	4	25
70~80	0	1	15	0	25
80~100	0	5	42	2	27
100~140	0	2	19	0	14

(b) Close to a bridge

PGV [cm/sec]	A	B	C	D	Total length [km]
~30	0	0	3	2	4.1
30~40	0	0	0	0	1.8
40~50	0	0	3	0	1.4
50~60	0	0	0	0	1.4
60~70	0	0	0	0	0.6
70~80	0	2	9	0	0.4
80~100	0	1	23	0	0.9
100~140	0	1	6	0	0.6

(c) Normal condition

PGV [cm/sec]	A	B	C	D	Total length [km]
~30	0	1	1	0	20
30~40	0	0	0	0	52
40~50	0	2	2	0	17
50~60	0	0	0	1	16
60~70	0	3	33	6	25
70~80	1	2	18	0	29
80~100	0	7	19	1	14
100~140	0	2	4	0	06

2.2. Fragility curve to estimate the number of damage

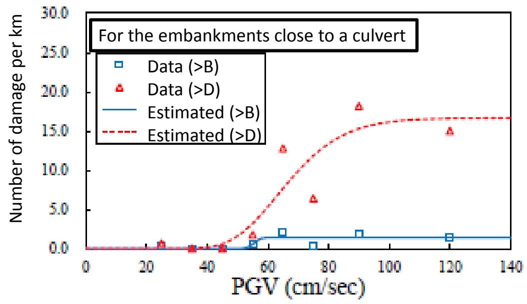
Based on the date shown in Table 1, fragility curves are discussed. Eq.1 is the equation assumed as the fragility function. Here, C is the number of multiplication for a usual type of fragility curve, and corresponds to the maximum number of damage for unit distance. Φ is the distribution function of normal distribution, λ and ζ are parameters to minimize the error function given by Eq.2.

$$P = C\Phi\left(\left(\ln PGV - \lambda\right)/\zeta\right) \qquad \text{(Eq.1)}$$

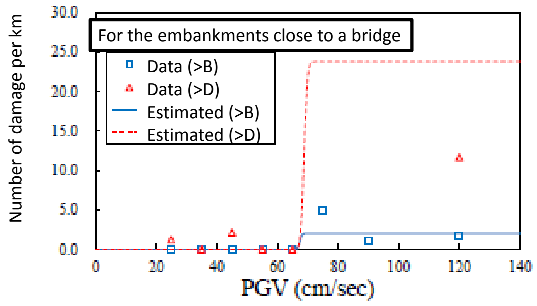
$$\varepsilon = \sum \left(P_R - P\right)^2 w \qquad \text{(Eq.2)}$$

P_R is the number of damage case per unit distance calculated by the real data, and w is the weight given by the total distance of express way in each PGV level.

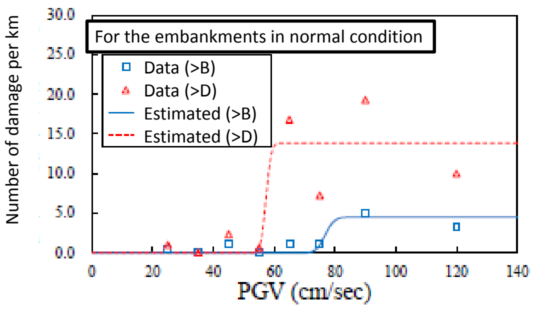
Figure 3 shows the calibrated fragility curves, and the parameters are summarized in Table 2. As shown in Figure 3, the maximum numbers of damage in the area close to a culvert are 1.4/km and 16.6/km for damage level more than B and damage level more than D, respectively. In the area close to a bridge, the maximum numbers are 2.1/km and 22.1/km for damage level more than B and damage level more than D, respectively. And for normal condition, the maximum numbers are 4.7/km and 14.2/km for damage level more than B and damage level more than D, respectively. However, the meaning of these values depends on the way to count the damage and relationship between the scale of damage and the number of damage, and it is difficult to discuss about it so far. The data of the scale of damage which relate to the restoration work is necessary to discuss about it.



(a) For the embankments close to a culvert



(b) For the embankments close to a bridge



(c) For the embankments in normal condition

Figure 3. Calibrated fragility curves for expressway embankment in various conditions

Table 2. Calibrated parameters for fragility curves for each embankment category

(a) Close to a culvert

	ζ	λ	C
>B level	**0.03**	**4.01**	**1.43**
>D level	**0.22**	**4.20**	**16.65**

(b) Close to a bridge

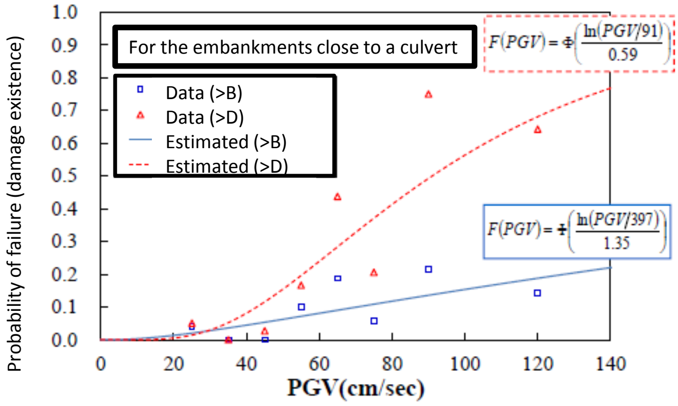
	ζ	λ	C
>B level	**0.01**	**4.21**	**2.11**
>D level	**0.01**	**4.23**	**23.80**

(c) Normal condition

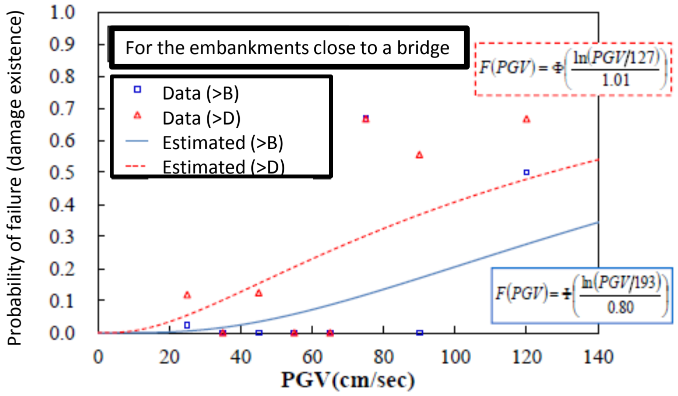
	ζ	λ	C
>B level	**0.03**	**4.34**	**4.50**
>D level	**0.02**	**4.05**	**13.87**

3. EVALUATION OF FAILURE PROBABILITY AT A CULVAER AND A BRIDGE

Although the discussion of the number of damage was difficult, failure probability can be discussed for all case within the vicinity of a culvert or a bridge. For this, whole culverts and bridges are picked up, and check whether there was damage in its vicinity (within 50 m) or not. And the number of culverts (or bridge) where damage was observed was divided by the total number of culverts (or bridges) for each PGV level. Figure 4 shows the results. For the practical seismic risk assessment, this fragility curve might be better for the evaluation of damage around culverts and bridges, because the definition of this fragility curves are more clear and correspond to realistic situation.



(a) For the embankments close to a culvert



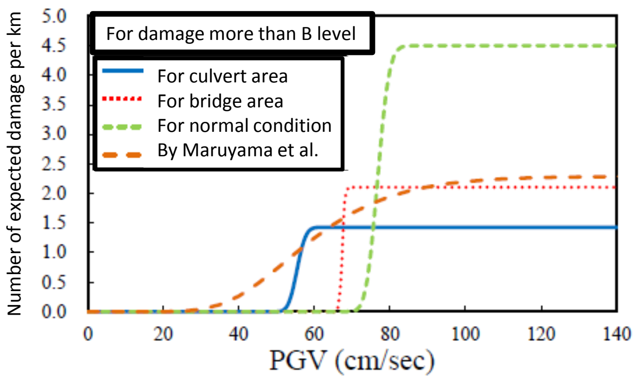
(b) For the embankments close to a bridge

Figure 4. Calibrated fragility curves for failure probability within the vicinity of structures

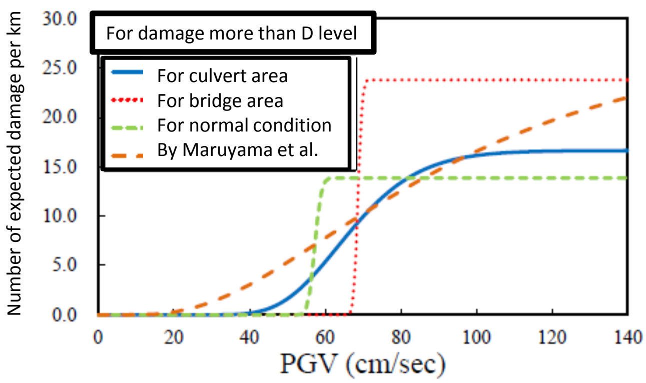
4. DISCUSSIONS

4.1. Comparison of fragility curves

Figure 5 shows the comparison of fragility curves. As shown in Figure 5, the curves proposed by Maruyama et al. (2010) are more flat that the curves proposed here. One of the reasons is that the curves calibrated by Maruyama et al. are based on the PGV distribution before the correction. For the damage level more than B, where difficulties for traffic might be observed, the threshold levels of PGV to cause damage are 50 cm/s, 65 cm/s and 70 cm/s for the area close to a culvert, area close to a bridge, and the area in normal condition, respectively. It indicates the damage occurrence is affected by the existence of structures, and the embankment close to a culvert tends to be damaged easily. Thus, the proposed fragility curves enable the consideration of the difference of embankment conditions in terms of the existence of a structure.



(a) Fragility curves for the damage more than B level



(b) Fragility curves for the damage more than D level

Figure 5. Comparison of the proposed fragility curves and the curve proposed by Maruyama et al. (2010)

4.2. Fragility curves for various conditions

One of the most unique points of this study is that it proposed a fragility curve for the normal condition, a symmetric shape of embankment with 5 m height, were constructed. In practice, the shape of embankment (height and width), ground conditions are different site by site. Therefore, it was really difficult to consider the difference of these conditions, because the observed damage is for the sites in these various conditions. However, since a curve was proposed for a unique clear condition, the fragility curves for various conditions can be discussed based on the comparison of the condition of the target embankment and the normal condition mentioned above.

The possible scheme to consider the difference of the embankment condition is as follows. FEM or Newmark sliding block method shall be applied to the embankment in various conditions to estimate the failure probability. Then, the ratio of failure probability of the embankment in the target condition to that of the embankment in normal condition shall be multiplied to the proposed fragility curves to assess the number of damage. If the failure probability can be evaluated adequately, the number of damage in various conditions easily estimated. However, one of the difficulties is whether FEM or Newmark method can appropriately assess the failure probability. A careful consideration for the mechanism of the failure occurrence in reality should be done for the future study on this purpose. But anyway, the fragility curves for expressway embankments in various conditions can be discussed from the research results.

5. CONCLUSIONS

In this study, based on the damage case history in Mid Niigata Prefecture Earthquake in 2004, an approach to propose the fragility curves considering the differences in various conditions for the expressway is discussed. Following conclusions are obtained.

1) Fragility curves to assess the number of damage per unit distance are proposed for the condition of vicinity of a culvert, or a bridge, or the normal condition (a symmetric shape of embankment with 5 m height).

2) Fragility curves to assess the damage occurrence probability are proposed for the condition of vicinity of a culvert or a bridge.

3) For the damage level more than B, where difficulties for traffic might be observed, the threshold levels of PGV to cause damage are 50 cm/s, 65 cm/s and 70 cm/s for the area close to a culvert, area close to a bridge, and the area in normal condition, respectively. It indicates the damage occurrence is affected by the existence of structures, and the embankment close to a culvert tends to be damaged easily.

4) Since a curve was proposed for a unique clear condition (normal condition), the fragility curves for various conditions can be discussed based on the comparison of the condition of the target embankment and the normal condition. A possible scheme was introduced.

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