

EVALUATION OF SEISMIC FRAGILITY FOR HIGHWAY TRANSPORTATION SYSTEMS

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SUMMARY

This paper presents a methodology for developing the seismic fragility function that takes both physical and functional aspects into account, and evaluates the seismic performance of a highway system as an example. It is well known that the seismic performance of transportation systems plays key rolls for the post-earthquake emergency management. It needs to be evaluated from both physical and functional view points. This paper deals with the fragility functions that can be used for post-earthquake management of transportation systems where both space and time factors are relevant. The basic data that describe physical and functional characteristics of the highway system under the 1995 Hyogoken-Nanbu earthquake was provided by Hanshin Expressway Public Cooperation. This paper (1) constructs the GIS-based damage database; (2) estimates spatial distribution of ground motions that is overlaid to the highway network to assign such ground motion to each facility; (3) develops the seismic fragility curves for the highway bridges. On the basis of the highway facility inventory, two types of highway bridge structure are considered: reinforced concrete bridges and steel bridges. For the fragility analyses of these types of bridges, a statistical model is employed. The seismic fragility curves are developed for collapsed, major damage, moderate damage, and minor damage situation, which are related to the periods of time needed for their recovery and reconstruction. The fragility curves resulting from this study evaluate both physical and functional aspects of the seismic performance for highway systems and are used to demonstrate for estimating seismic losses due to earthquakes.

INTRODUCTION

It is well known that the seismic performance of transportation systems plays key rolls for the post-earthquake emergency management. At the 1995 Hyogoken-Nanbu (Kobe) earthquake, the failure of transportation systems results in delaying and/or malfunctioning the emergency response operations such as fire fighting or search and rescue activities. Hence, the seismic performance of transportation systems is one of the most important research topics in the lifeline earthquake engineering. And it needs to be evaluated both physical and functional aspects. The physical aspects of the seismic performance are evaluated with the seismic fragility functions or damage probability matrices of transportation facilities. And the functional aspects of the seismic performance are evaluated in many ways such as restoration curves, connectivity of a system, remaining traffic flow, etc.

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This paper deals with such fragility functions that can be used for post-earthquake management of highway transportation systems where space and time factors are relevant. The fundamental data that describes physical and functional characteristics of the highway systems under the 1995 Hyogoken-Nanbu earthquake was provided by Hanshin Expressway Public Cooperation. Although the structural damage of the Hanshin expressway is widely distributed in both Kobe and Osaka area, most of the research efforts have been focused only on Kobe area where the most serious damage occurred. However, from the operational point of view, the minor damage occurred in Osaka area that causes a road closed is important as well. Therefore, in this paper, first, the physical and functional damage database for the Hanshin expressway due to the Kobe earthquake in both Kobe and Osaka area is constructed utilizing GIS. Then, the fragility functions for the highway bridges are developed by each structure type, and are evaluated in comparison with the probabilistic damage matrices in ATC-13 [ATC-13, 1985].

2. DEVELOPMENT OF DAMAGE DATABASE

2.1 Hanshin Expressway Damage Situation

The Hanshin Expressway network covering the Kansai metropolitan area is depicted in Fig. 1. The total length of the network is approximately 221km and the amount of traffic is over 1 million vehicles per day (As of 1998).

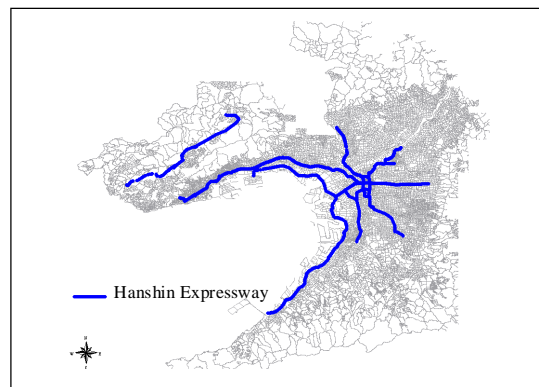


Fig. 1 Hanshin Expressway Network

By the Kobe earthquake, the network was severely damaged. Right after the earthquake, the emergency inspection was carried out to grasp the overview of the damage. After that, more detailed inspection was carried out for constructing the repair strategies and estimating the restoration time for all structures.

The inspection was focused on structural damage and road surface condition. The structural damage index is focused on the evaluation of remaining earthquake resistance of the structure and is classified into 5 categories; they are collapse (As), major damaged (A), moderate damage (B), minor damage (C) and no damage (D) respectively. The road surface condition is focused on the damage of expansion joint, road roughness, and is classified into 3 categories; they are impossible to driving (a), possible to driving with some problems (b) and possible to driving without any problems (c) respectively. The typical structural damage in each category is illustrated in damage charts [Japan Road Association, 1988]. Figure 2 shows an example of the chart which corresponds to the actual damage photo. The total damage index that would give the fundamental information to decision making whether the road remains to open or close is integrated in these two indexes. Based on the inspection, 4211 highway bridges for 8 routes are identified. So that these bridge locations are digitized utilizing GIS. And the feature of each bridge such as structure type, skew, damage level, and other information is related to the attribute table in the database as shown in Fig. 3.

2.2 Ground Motion

The fragility curve of a structure describes a relationship between a ground motion and a level of damage. To evaluate such relationship accurately, the ground motion estimation at each site where the target structure locates is vital. There are many indices that represent the magnitude of ground motion suitable for fragility analysis, such as peak ground acceleration (PGA), peak ground velocity (PGV), the instrumental JMA (Japan Meteorological Agency) seismic intensity, etc. Among them, PGA is widely used as an index for fragility curve. However, the ground motion records of the Kobe earthquake are very limited. Although many researchers have

proposed the estimated PGA distribution over the impacted area, the resolution is still not sufficient for such purpose.

震害調査の種類	① 橋脚の柱脚部	② 橋脚の柱脚部(橋脚上部)	③ 橋脚の柱脚部(橋脚下部)	④ 橋脚の柱脚部(橋脚上部)	⑤ 橋脚の柱脚部(橋脚下部)	⑥ 橋脚の柱脚部(橋脚上部)
橋脚の柱脚部	震害調査					
	震害調査					
橋脚の柱脚部(橋脚上部)	震害調査					
	震害調査					
震害調査	C:1.0橋脚	C:1.0橋脚	C:1.0橋脚	B:1.0橋脚	B:1.0橋脚	A:1.0橋脚
震害調査	100%	50%	30%	10%	5%	0%

Fig. 2 Damage Chart for Highway Bridge Structure

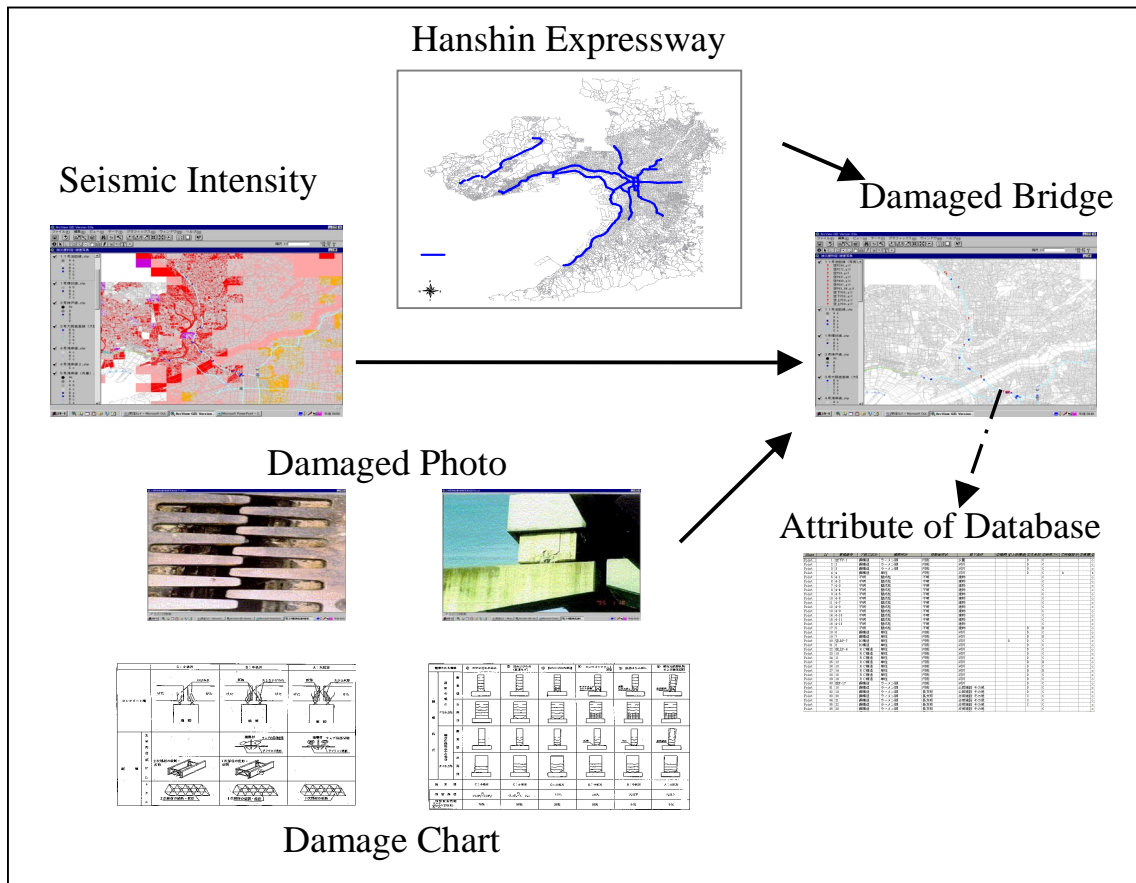


Fig. 3 GIS Damage Database

In this study, the seismic intensity determined by questionnaire survey is introduced as the ground motion index. The methodology of the seismic intensity based on questionnaire survey is originally developed by Ohta [Ohta, et al., 1979] and the capability has been evaluated for applying past earthquakes [Ohta, et al., 1998]. The value of this seismic intensity is corresponded to the value of the instrumental JMA seismic intensity, so that the advantage of this method is to obtain the ground motion distribution with higher resolution after the earthquake. At the Kobe earthquake, the questionnaire survey is carried out by some research groups. In this study, the seismic intensity map for Kobe area is provided by Kobe University [Takada et al., 1998] and for Osaka area is provided by Geo-Research Institute, Osaka [Tsurugi et al., 1999]. The intensity is summarized by jurisdictions (cho-cho-moku) for Kobe area and about 1km mesh for Osaka area. In the intensity map, there are some

jurisdictions or meshes that do not have the intensity information. These are the jurisdictions or meshes nobody lives in; for example, park, factory, school, etc.

3. DEVELOPMENT OF FRAGILITY CURVES

The digital map of the highway network developed above is overlaid the distribution map of the seismic intensity, so that the seismic intensity value can be assigned to each bridge. As the result, 528 bridges out of 4211 are not assigned to the intensity since these bridges are located in the jurisdictions or meshes without the intensity information. Table 1 and Fig. 4 summarize the structural damage of the highway bridges by structural type, and the locations of the bridges are plotted in Fig. 5 with the distribution of the seismic intensity.

Table 1 Summary of Damage

Structure Type	Damage Index					Total
	As	A	B	C	D	
PC	0	1	3	286	0	290
RC	58	90	140	2438	356	3082
SRC	0	0	1	7	0	8
Steel	4	35	88	660	25	812
Unknown	0	0	1	18	0	19

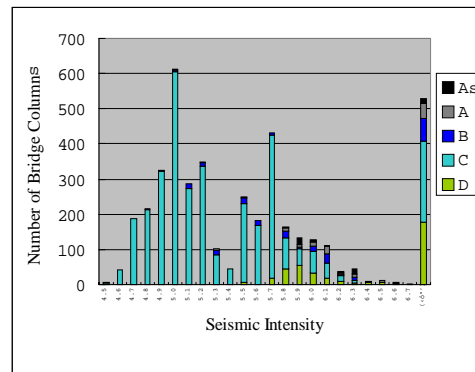


Fig. 4 Number of Damaged Bridge by Seismic Intensity

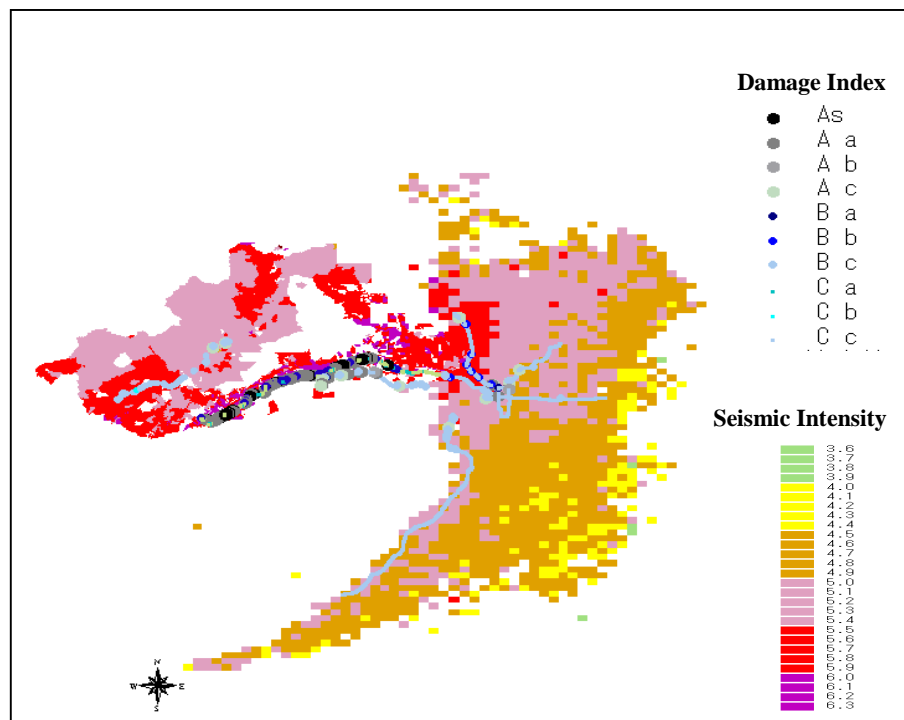


Fig. 5 Damaged Bridges and Seismic Intensity

The fragility curves for bridges are constructed assuming normal distributions for the cumulative probability of occurrence of the damage equal or higher than level R at the seismic intensity I as follows:

$$P_R(I) = \Phi\left(\frac{I - \mu}{\sigma}\right)$$

Where Φ is the standard normal distribution and μ and σ are the mean and standard deviation of I respectively. The two parameters of the distributions are determined by the linear regression analysis plotted on the normal probability paper and the results are listed in Table 2.

Table 2 Coefficients of Fragility Curves

	RC		Steel		PC	
	μ	σ	μ	σ	μ	σ
>B	6.66	0.77	6.79	1.18	6.05	0.20
>A	6.69	0.69	8.10	1.61	N/A	N/A

The fragility curve is usually represented by ground acceleration and level of damage. Hence, the seismic intensity I is converted into PGA as follows [Tong, et al, 1996]:

$$PGA = 10^{-0.23+0.51I}$$

Figure 7 and Figure 8 show the fragility curves for the steel and RC bridge structures comparing with the damage probability matrix for conventional bridges of ATC-13 [ATC-13, 1985].

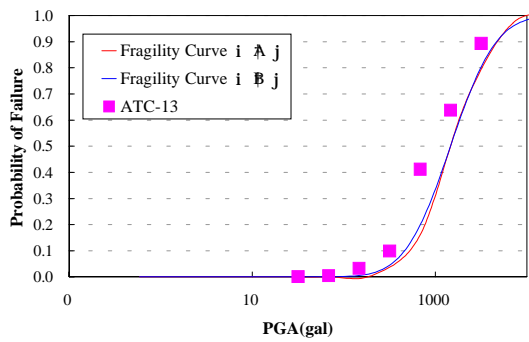


Fig. 7 Probability of Failure for RC Bridge

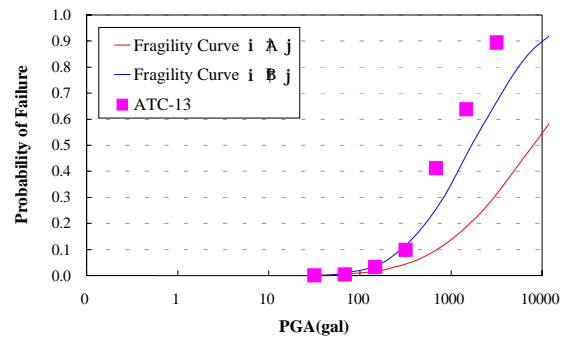


Fig. 8 Probability of Failure for Steel Bridge

It shows that the damage probability matrix of ATC-13 is more fragile than the fragility curves developed here. This may be due to the difference in the definitions of damage levels used in ATC-13 and in this study. It is also possible that the converted PGA values using the MMI-acceleration relationships may be exaggerated. As for the RC structure, the difference between the damage A and B is not clear. This may be due to the data distribution, so that the further study is needed to identify these effects.

4. CONCLUDING REMARKS

The evaluation of seismic fragility for highway transportation systems is presented in this paper. Utilizing the actual damage data provided by Hanshin Expressway Co. at the 1995 Hyogoken-Nanbu earthquake, the damage database is constructed with GIS. With this database, the fragility curves are developed assuming normal distributions and are evaluated in comparing with the probability damage matrix of ATC-13. Although the fragility curves developed here are still tentative, they would be useful in damage simulation.

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