Statistical Seismic Risk Analysis of the Highway Bridges

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Synopsis

Lifecycle seismic risk of existing highway bridge piers which were retrofitted after the Hanshin Earthquake, have been estimated by probability analysis. Hazard and fragility curves for the seismic risk analysis and also a category of damage rank and recovery cost are explained practically, those are essentially required for the estimation. The obtained results and also some issues to be solved for the near future are described consequently.

KEY WORDS: Seismic Risk, Hazard Curve, Fragility Curve, Execution Cost Estimation

1. Introduction

Cost minimum based strategy is strongly required nowadays for the maintenance of infrastructures. Life cycle cost assessment is essential for decision making when and how to maintain and for priority which facility to implement. The stages for the life cycle cost assessment are generally construction, maintenance and reconstruction. In addition to those, it should be also essential to consider the possible impact of earthquake, which might occur during service period.

In this paper, a seismic risk of highway bridges in urban area has been evaluated as value of money, which is helpful for decision making. Money value quantifications of the possessing risk and of the countermeasure are effective for the strategic maintenance program in practice. The seismic risk is generally consisted with direct cost due to recovery of the infrastructure itself and indirect cost due to social loss by the deterioration of its network function. The present study focuses only the former cost.

2. Seismic Risk Assessment Procedure

As shown in Fig.1, there are three essentials in the seismic risk analysis as follows: The first is a hazard curve for earthquake occurrence probability, the second is a fragility curve for damage rank and its probability of structure due to earthquake, and the last is an expectable value loss relevant to each of the damage rank

The hazard curve used herein was as shown in Fig. 2, which has been proposed by JSCE available allover Japan. Moreover, the fragility curve was obtained as follows: First, The strengths of existing highway bridge piers were estimated considering confinement effect on concrete; Second, the displacement responses of the piers was calculated by dynamic response analyses; Last, the fragility curve and also damage density distribution were

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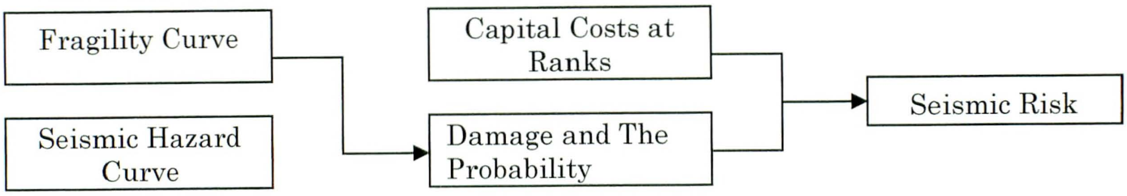

Figure 1. Flow of seismic risk estimation

drawn supposing that the displacement responses could accord to lognormal distribution. Furthermore, the expectable value loss was defined based upon the restoring expenses of highway viaducts, consisting piles and a T-shaped pier, at Hyogoken Nanbu Earthquake in 1995.

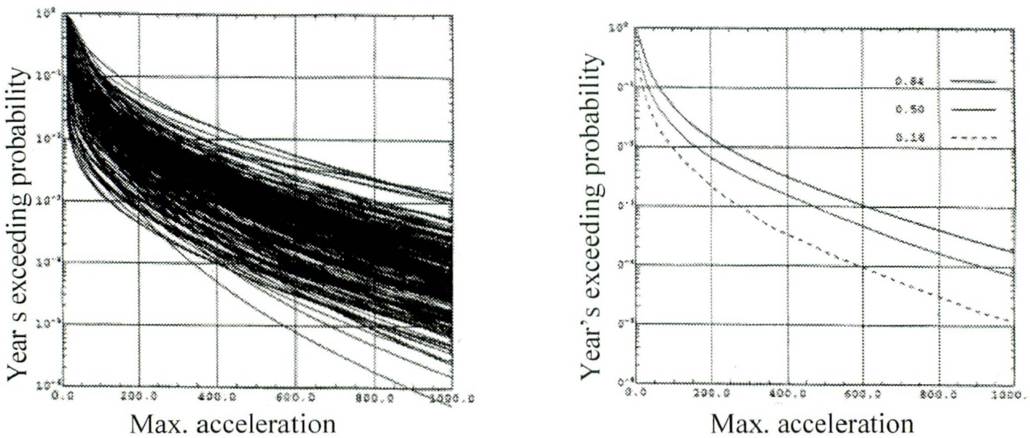

Figure 2. Seismic hazard curve[3)]

Consequently, the probability of the damage due to earthquake was a product of the probabilities of occurrences of earthquake by the hazard curve and damage by the fragility curve and the seismic risk can be estimated by multiplying the obtained product by the expectable value lost.

3. Existing Bridge Piers to be analyzed

The structures to be analyzed are existing highway bridge piers in urban area, which have been already retrofitted by steel jacketting due to seismic code change after the Hansin Earthquake, however, the focusing point in the present study is to estimate seismic risk against the larger earthquake in the future. The execution costs for the piers reconstruction and strengthening due to earthquake damage a year and fifty service periods were only considered, except for the cost for the girders due to earthquake damage and ordinary maintenance cost.

All the highway bridge piers for analyses are of reinforced concrete, while the corresponding bridge girders are of reinforced concrete or steel. Various five piers among them, listed in Tab.1, were selected with deferent height, cross-sectional size and the individuality which will be describe in section 5.2. The pier height at the analysis was defined as the length from the bottom of deck slab to the top of foundation, in which an inertia force due to earthquake was applied at the top of the pier. Thus, the solution has a safety margin because a gravity center of the superstructure is generally located above the bottom of the deck slab.

Table 1. Detail of bridge piers

Bridge Piear	Beam	Height (m)	Square cross-Section (mm)	Static nonlinear individuality				
				Yielding load (kN)	Yielding Seismic Intensity*	Maximum load (kN)	Maximum Seismic Intensity*	Ultimate displacement (mm)
T1	RC	12.7	2400	2577	0.35	3696	0.50	302
T2	Steel	11.2	2000	1864	0.40	2612	0.55	272
T3	Steel	11.2	2000	1781	0.36	2228	0.45	438
T4	Steel	11.2	2300	2582	0.47	3700	0.67	304
T5	Steel	11.1	2300	2256	0.47	3181	0.66	354

* Failure seismic intensity is defined as the ratio between failure load and weight, while maximum seismic intensity is defined as the ratio between maximum load and weight

4. Seismic Hazard Curve

In Fig.2, the left graphic shows seismic hazard curve in the 246 places distributed around Japan. For each acceleration, a curve which has larger probability than the 84% curves was drawn, and named as 0.84. At this research, considering the reinforcement, the curve named 0.16 was chosen to estimate the min. seismic risk.

5. Fragility Curve

5.1 Confinement effect of concrete

In an ordinary structural design of concrete, the uniaxial stress and strain relation as broken line in Fig. 3. However, an alternative solid line in the figure was recommended lately in the specification of highway bridge design in Japan, which was reflected on the confinement effect of concrete due to shear reinforcement. The effect can lead the improvement of the strength and deformability of reinforced concrete structural members. The maximum effect was expected in this study, because the referred existing bridges had a sufficient shear reinforcement.

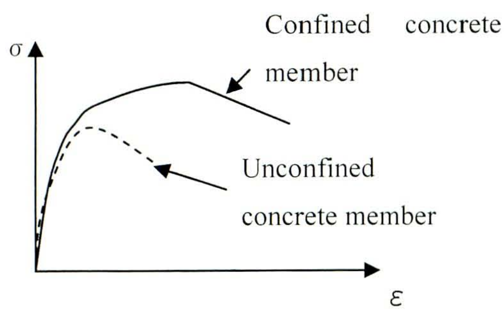

Figure 3. Example of uniaxial stress-strain curve for confined concrete

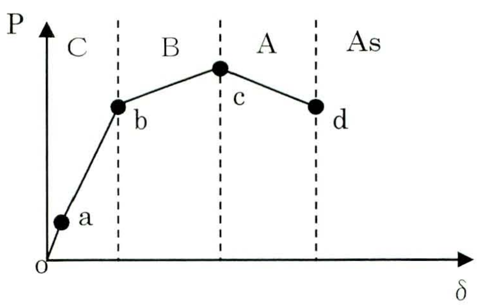

Figure 4. Damage rank on load-displacement curve

5.2 Load-deflection curves and hysteresis of the piers

Fig.4 shows the idealized multi linear load-deflection curve introduced by a nonlinear analysis program used herein. Each slope were determined as follows: First, at the point a in the figure, cracking of concrete initiates; Second, at point b, tensile reinforcement yielded and the yielding load achieved; Third, at point c, maximum strength attains; Last, at point d of ultimate state defined by the compressive failure of concrete. Furthermore, four damage ranks according to deflection level were categorized into C, B, A and As.

5.3 Time response analysis

Time response analysis is a kind of dynamic analysis, with the proper period and ground motion due to earthquake as parameters. To raise the reliability of the analysis, number of practical pier models with various and reasonable proper periods were derived from the existing five piers, altering their yielding intensity. In Fig.5, in actually the piers with the same shear strength have different bending strength from each other around 10%, accordingly we changed yielding intensity among $\alpha \pm 0.1$(α as the initial yielding intensity). The alteration results are shown in Fig.6.

As the another parameter, 6 kinds of design seismic waves for the second-category foundation have been prescribed by the existing specifications for highway bridges, in which three of them are called Type 1, and the rest are called Type 2. We adjusted the earthquake intensity from 100gal to 1000gal with 100gal increment in between. Thus, there are 60 seismic waves available.

The estimation results of the pier T5 are shown in Fig.7.

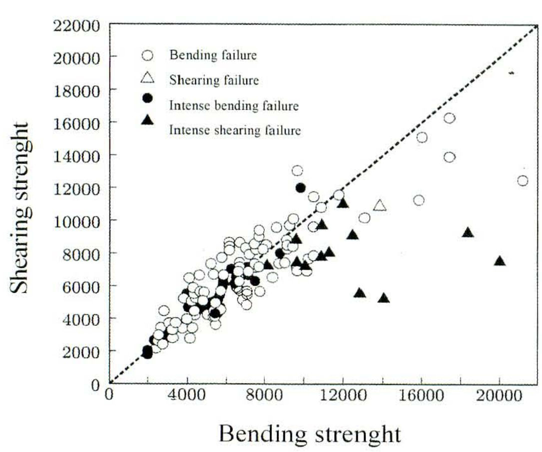

Figure 5. Shear and bending strengths of existing highway bridge piers in Hanshin earthquake[5)]

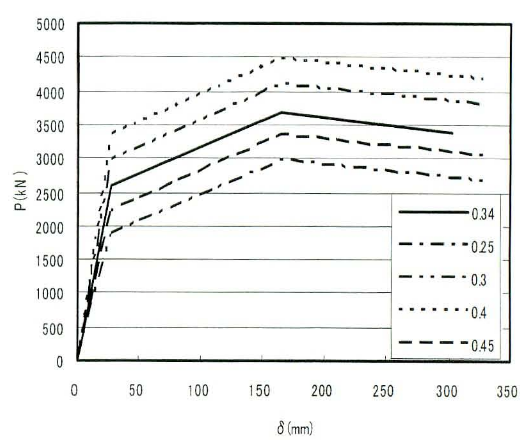

Figure 6. The alteration results of yielding seismic intensity

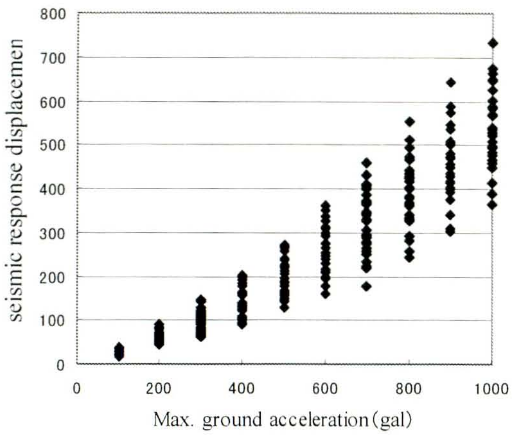

Figure 7. Distribution of response displacement

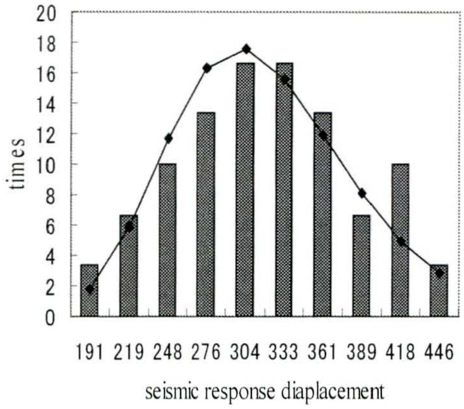

Figure 8 Distribution of displacements

5.4 Seismic fragility curve

It is essential, for the five existing piers, the corresponding damage rank previously described in section 5.2. Table.2 shows the definition of the damage ranks.

For each of the prescribed acceleration on ground surface, the corresponding series of the calculated responses displacement, take the results of 700gal shown in Fig.7 as an example, were approximated to be distributed lognormally, as shown in Fig.8. The approximated distribution were, further more, subdivided into four of the damage ranks of As, A, B and C as shown in Fig.9, in which the subdivided curves were integrated as to be the occurrence probability of each damage rank. The fragility curves shown in Fig.10 have been obtained as the whole results of the probabilities, carrying out the same procedure as to data in Fig.7 of other accelerations.

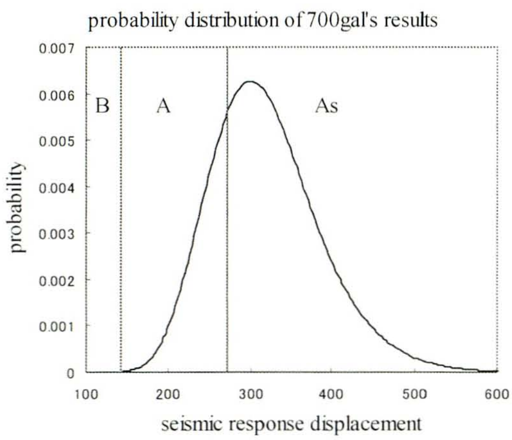

Figure 9 Lognormal distribution

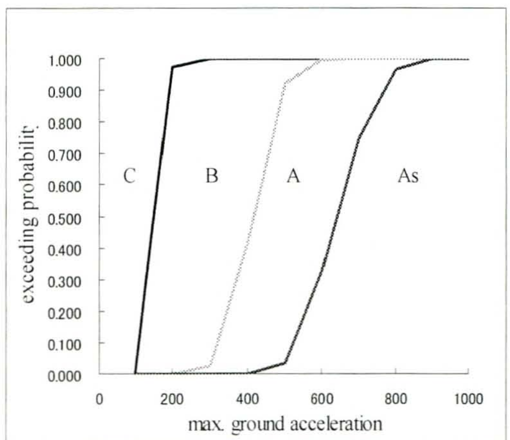

Figure 10 Fragility Curve

Table 2. Category of damage rank based upon displacement states

Damage Rank	Displacement	Definition
A_s	Ultimate	Collapsed or seriously deformation
A	at The Maximum Load	Rupture of re-bars and Significant deformation
B	At Yielding Load of re-bars	Crack and partial peeling of cover concrete
C	Elastic	Minor damage, i.e., crack initiation

6. Cost at Ranks of Seismic Damage and Seismic Risk

According to reference 4, the restoring method and cost for each damage rank were indicated and shown in Tab.3. From chapter 4 to 6, all of three essentials were prepared, *P(a)* as the probability of earthquake, *p(b|a)* as the probability of level b damage when earthquake a occurs, at last *cost(b)* as the repairing cost of level b indicated at Tab.3. The seismic risk is able to be calculated with the equation 1 and 2. The results are in Tab.4 with the interest rate 0.02.

Table 3. Restoring method and cost for each damage rank

Damage rank	Retrofitting design			Recovery cost
	New-Construction	Repairing	Strengthening	
As A	Removal of existing pier and Construct new pier with sufficient seismic performance	-	-	15.8
B	-	Removal of damaged concrete, Repair of deformed re-bars and Fill up of cracks with resin	Steel or concrete jacketing	2.8
C	None			0
	New construction			1

$$risk = \int_0^{1000gal} P(a) \times \sum_{Dam.} \left[p(b/a) \times cost(b) \right] \quad (1)$$

$$risk50 = \sum_{i=0}^{49} \left[risk / (1+0.02)^i \right] \quad (2)$$

Table 4. Estimation results

Tag	Percentage of average cost Yearly(risk)	Percentage of total cost for 50 years usage(risk50)
T1	4.07%	125%
T2	4.40%	136%
T3	4.43%	134%
T4	3.57%	110%
T5	3.38%	104%

The damage possibilities of the existing highway bridge piers in the urban area due to earthquake and also the relevant cost for recovery.

As Fig.11 showed, as to the tendency of estimated cost a year for each damage rank, it was naturally found that the cost for damage ranks As and A was expensive. It was due to the need of the removal and reconstruction based on the practical experience at the Hanshin Earthquake.

While Fig.12 shows us the seismic risks of different piers, it also could be pointed out that the seismic risk of the pier under eccentric vertical load was relatively less occasionally designed with larger ultimate strength.

The contain of seismic risks for different piers as shown in Fig.13 and the list of the cost for the rank A and B categories took larger percentage.

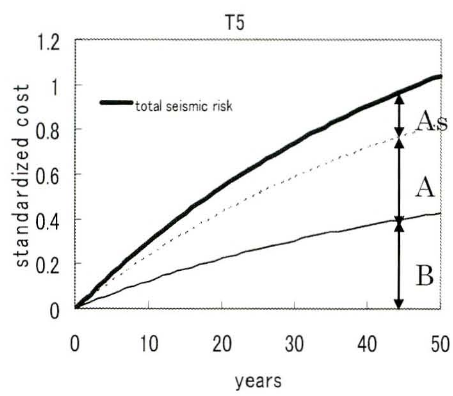

Figure 11. Seismic Risk by Ranks

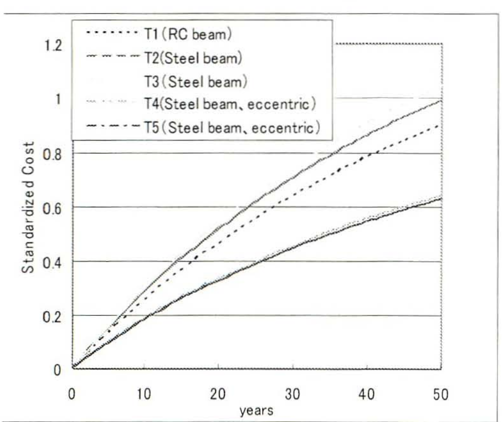

Figure 12. Seismic Risk by years

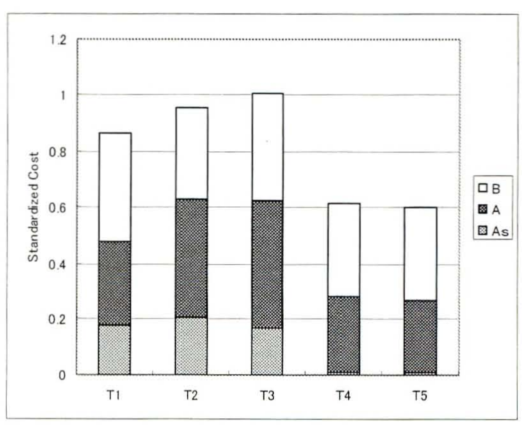

Figure 13. Contents of Seismic Risk of Different Pillars

7. Concluding Remarks

In this paper, with detail expectation of hazard curve, fragility curve and prospective recovery cost, the min. seismic risk of the highway bridges, which are supposed to be adequately strengthened, were estimated. From the results, it can be seen that

(1) the piers of steel beam have larger seismic risk than the ones of concrete beam.

(2) It is also obviously that A and B ranks take the larger percentage of the total seismic risk..

(3) The total risk will increases with a yearly reduced pace.

As issues to be solved, first, load-displacement relationship of the bridge piers should be improved considering foundation. Second, definition of both damage rank and corresponding cost should be more precisely considered. Last, hazard risk should be improved reflecting locality.

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