BRIEF NOTE

EVALUATION OF SEISMIC SAFETY OF EXISTING BRIDGES

by

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SYNOPSIS

Statistical analysis was made on the effects of various characteristics of bridges on their seismic damage. Based on the results thus obtained, a simple criteria was proposed for the evaluation of seismic safety (or vulnerability) of existing bridge structures with particular emphasis on the fall of superstructures.

METHOD

Thirty bridges damaged to different degrees by the 1923 Kanto, the 1948 Fukui and the 1964 Niigata earthquake were selected as samples. Fourteen bridges were those collapsed (including five bridges which almost collapsed), i.e. spans fell off their supports, while the rest were damaged but did not collapse. Degree of damage was evaluated by referring to post-earthquake reconnaissance reports, and a numerical value assigned. Let the assigned degree of damage of sample i be denoted by A_i. Values of A_i varied from 2 to 5 for the collapsed bridges, and from 0.8 to 1.5 for the rest.

Then, items characterizing the properties of a bridge were identified that were likely to have influenced the degree of damage. After several preliminary analyses, a total of nine items were selected. They are shown in the first column of Table 1. Each item was divided into two or three categories. Selection of categories was inevitably affected by the characteristics of the sample set used for analysis. For example, samples did not include a damaged bridge built on Type I ground, which is defined as Tertiary or older rocks and dense and thin diluvial layers. Since two samples were arch-type bridges and the rest were simple-beam or cantilever-beam-type bridges, there are only two categories

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in item 3. As shown in Table 1, there are a total of 22 categories for the nine items.

Define a variable X_{ijk} corresponding to category k in item j of sample i. This variable takes a value of 1 (one) if the properties of sample i corresponds to category k for item j, and 0 (zero) otherwise. In other words, though there are 22 such variables for each sample, only nine of them have values of 1 and the rest are 0. Denote the weighting coefficient of category k in item j by W_{jk}, and consider

$$\alpha_i = \prod_{j=1}^{9} \prod_{k=1}^{2 \text{ or } 3} W_{jk}^{\;X_{ijk}} \tag{1}$$

It was assumed that, if appropriate values were determined for weighting coefficient W_{jk}, Eq. (1) gives an estimate of the degree of seismic damage sustained by a bridge with the characteristics defined by a set of variables X_{ijk}. Values of W_{jk} are so determined that the calculated degrees of damage α_i's of the thirty samples best agree with their assigned degrees of damage A_i's. Replacing α_i by A_i and taking logarithms of both sides of Eq. (1) yield a set of linear simultaneous equations with unknowns $\log W_{jk}$. Therefore, the solution procedure is essentially similar to the least-square solution of linear simultaneous equations except for the fact that the variables X_{ijk} are subject to the following relation

$$\sum_{k=1}^{m} X_{ijk} = 1 \tag{2}$$

where m is the number of categories in item j, namely m = 2 or 3 in the present analysis.

RESULTS

The values of weighting coefficients determined by the above-mentioned method are shown in Table 1. Since the number of samples was not sufficient and the quality of samples seems to be rather biased, the result in Table 1 shows several tendencies which are contradictory to what an ordinary earthquake engineer would expect from experience. Though ground condition generally becomes worse as it goes from Type II to IV, the weighting coefficient of Type III (1.86) is greater than that of Type IV (1.60). Such inconsistency is also seen for the categories in item 5. Therefore, if a criteria is derived from these results of statistical analysis, it is necessary to modify them by taking account of experience and engineering judgment.

In the last column of Table 1 are shown the ranges of weighting coefficients for the nine items. The range of any item is defined as the ratio of the maximum weighting coefficient to the minimum in the item under consideration. The greater the value of range of an item is, the more important effect the item has on the degree of seismic damage to bridges. It is seen that type of superstructure, severity of ground shaking, liquefaction potential and ground condition of the site are the more important factors for the seismic safety of bridge structures.

Fig. 1 shows the correlation between the assigned and the calculated degrees of seismic damage. With a few exceptions, the calculated (or estimated) degree of damage is within ±30% of the assigned value.

CRITERIA

In order to derive a criteria for the evaluation of the seismic safety of existing bridges in general, account should be taken of the followings:

(1) A value should be assigned for the weighting coefficient of Type I ground. Type II, III, and IV ground approximately correspond to thicker diluvial or thinner alluvial layer, alluvial layer most commonly found in Japan, and very soft and weak layer, respectively.

(2) A value should be assigned for the weighting coefficient of continuous-span bridges.

(3) A value of the weighting coefficient should be assigned for bridges in which special care is paid for preventing spans from falling off their supports.

(4) Width of substructure's crest should be considered in connection with the length of span. The Specifications for Earthquake-Resistant Design of Highway Bridges (Japan Road Association, 1971) provides the minimum length, S (cm), between end of bearing and edge of substructure's crest as

$$S = 20 + 0.5\,\ell \qquad \text{for } \ell \leq 100$$

$$S = 30 + 0.4\,\ell \qquad \text{for } \ell \geq 100$$

where ℓ is span length in meters.

(5) Though the effect of material used for abutment or pier

was not noticeable for the samples used (not included in the final analysis shown in Table 1), this item should be included in the criteria, which will be used for both older and newer existing bridges.

By taking into account the above-mentioned matters and practicing engineering judgment based on experience, a criteria is tentatively proposed in Table 2. Adequacy of the weighting coefficients in items "Superstructure's type", "Type of bearing", "Number of spans" and "Width of substructure's crest" was examined by comparing the relative order of seismic safety obtained by the criteria for various types of bridges having practical combinations of categories in these items. The result is not shown here but was found satisfactory. Then, this criteria was applied for the thirty sample bridges originally used for statistical analysis. It was found that the bridges collapsed during past earthquakes had values of the product of ten coefficients greater than 30 for most cases. Therefore, it is tentatively proposed here that, if the product obtained by the criteria shown in Table 2 is greater than 30, the bridge should be considered quite vulnerable to seismic effects and the possibility of its girders to fall off their supports is relatively high.

It should be noted that this simple method is intended to be used for a preliminary safety evaluation only. More rigorous and complicated analyses should be made for those bridges whose seismic strength is judged dubious by the simplified method presented here.

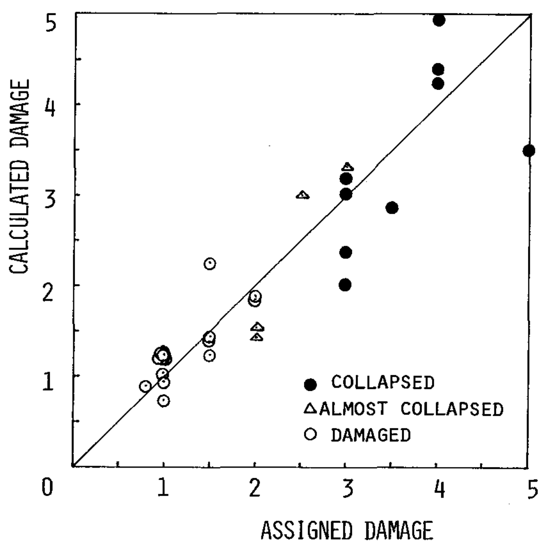

Fig. 1. Correlation between assigned and calculated damage

Table 1. Results of Statistical Analysis

ITEM		CATEGORY		WEIGHTING COEFFICIENT	RANGE
j	NAME	k	NAME		
1	Ground Condition	1	Type II	1	1.86
		2	Type III	1.86	
		3	Type IV	1.60	
2	Liquefaction Potential	1	None	1	2.01
		2	High	2.01	
3	Type of Superstructure	1	Arch	1	3.00
		2	Simple or Cantilever	3.00	
4	Type of Bearing	1	Ordinary	1	1.15
		2	Both Bearings on a Pier Movable	1.15	
5	Max Height of Abutment or Pier	1	Less than 5 m	1	1.72
		2	Between 5 and 10 m	1.72	
		3	Greater than 10 m	1.68	
6	Number of Spans	1	One	1	1.75
		2	Two or More	1.75	
7	Width of Sub-Structure's Crest	1	Less than or Equal to 1.4 m	1	1.25
		2	Greater than 1.4 m	0.80	
8	Severity of Shaking in M.M. Scale	1	IX	1	2.64
		2	X	2.41	
		3	XI or More	2.64	
9	Foundation	1	Pile Bent	0.15	1.36
		2	Pile Foundation	0.11	
		3	Columns of a Pier on Independent Wells	0.11	

Table 2. Simple Criteria for Evaluating Seismic Safety of Existing Bridges with Special Reference to Falling-Off of Superstructures

ITEM	CATEGORY	WEIGHTING FACTOR	REMARKS
Ground Condition	Type I	0.5	Classification of ground as specified in SERDHB*; Ground condition becomes worse as it goes from I to IV.
	Type II	1.0	
	Type III	1.5	
	Type IV	1.8	
Liquefaction Potential	None	1.0	Classification follows as specified in SERDHB.
	Moderate	1.5	
	High	2.0	
Type of Super-Structure	Arch or Rigid-frame	1.0	
	Continuous Beam	2.0	
	Simple or Cantilever	3.0	
Type of Bearing	With Anti-seismic Devices	0.6	
	Ordinary	1.0	
	Both Bearings on a Pier Movable	1.15	
Max Height of Abutment or Pier	Less than 5 m	1.0	
	Between 5 and 10 m	Linear Interpolation	
	Greater than 10 m	1.7	
Number of Spans	One	1.0	A continuous beam is counted as one span.
	Two or More	1.75	
Width of Sub-structure's Crest, and Length of Suspended Joint	$A/S \geq 1$	0.8	A=Length between end of bearing and edge of sub-structure. S=Min value in SERDHB.
	$A/S < 1$	1.2	
	$D \geq 1$	0.8	D=A/60 (Ground I to III) D=A/70 (Ground IV) A=Length of suspended jt.
	$D < 1$	1.2	
Severity of Shaking in M.M. Scale	IX	1.0	
	X	2.4	
	XI or More	3.5	
Foundation	Other than Pile Bent	1.0	1.4 is used for evidently weak foundations like friction piles.
	Pile Bent	1.4	
Material of Abutment or Pier	Masonry or Plain Concrete	1.4	
	Other than Above	1.0	

*SERDHB = Specifications for Earthquake-Resistant Design of Highway Bridges (Japan Road Association, 1971).