QUANTITATIVE EVALUATION OF ANTISEISMICITY OF BRIDGES

by K. KUBO

SYNOPSIS

The writer presented his paper on a simple method for evaluating seismic safety of existing bridge structures to 6 WCEE 1977[1]. By his opinion, there was one demerit related to the weighting factors for the term of seismic intensity. In this paper, the writer proposed the revised distribution of the weighting factors by changing weighting factors for seismic intensities, and he tried to investigate antiseismicity of existing bridges by use of his score-table when the construction sites, type of bridges and seismic intensities are variable. It is concluded that the seismic damage ratio of bridges in Tokyo will be about 5%, when Tokyo is attacked by an earthquake whose seismic intensity in Tokyo is IX by modified Mercalli scale, and change of construction types of bridges is very effective for decreasing seismic damage ratio of bridges.

INTRODUCTION

In the previous paper, the writer proposed the new method for evaluating antiseismicity of existing bridges and calculated the weighting factors for each category by use of quantification theory and data on the bridges damaged by past earthquakes.

There were three aspects to be amended in the calculation results mentioned above from the viewpoint of engineering judgement. The first one is the weighting factors allotted to soil conditions of alluvial soils and very soft soils which are 1.86 and 1.60 respectively. In the simple method of evaluation proposed by the writer, it is concluded that the higher the score, the less the antiseismicity of the bridge. This calculation result is somewhat contradict to common knowledges of civil engineers, because in the past earthquakes seismic damage ratio of the bridges on alluvial soil layers is smaller than that on very soft soil layers.

The second aspect is like that quantification theory can give us only its answer of weighting factors for each corresponding category, but not for any category which has no correspondence to the samples of damaged bridges. For example, there was accidentally no damaged bridge on rock ground (1st kind of soil condition in the table of categories.) among the samples of damaged bridges, and that is why there is no computed weighting factor for rock ground, in Table-1. The last aspect

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is very close to the second point. The data used for calculation of weighting factors were old-type bridges, and therefore weighting factors for continuous type bridges, rigid frame bridges, and bridges with special devices of preventing falling-down of girders can not be obtained by the calculation procedures mentioned above.

These points of demerit have been eliminated by taking into account the special characteristics on the dynamic behaviors of bridges in the past earthquakes, and thus the revised score table has been proposed. The new table has been applied to evaluation of antiseismicity of 260 existing bridges in Tokyo and usefulness of the new table has been confirmed with the result in which about ten bridges are judged to be vulnerable in the event of an earthquake of seismic intensity IX .

These bridges judged as low antiseismicity were checked by the usual method, which had as similar conclusions as the simple evaluation method.

In the above-mentioned confirmation procedure, the seismic intensity is always the same as IX by modified Mercalli scale, and therefore the mistake of weighting factors for the term of seismic intensity has been hardly recognized so far. Damage ratio of buried water pipes, which is number of collapses per unit length of buried pipes, increases very rapidly with increase of ground acceleration which is rougly corresponding to seismic intensity. However the weighting factors for seismic intensity IX, X and XI were 1.0, 2.41 and 2.64 in the previous paper, respectively. The curve of A in Fig.1 shows relations between damage ratios of buried pipes and seismic intensity and the curve of B shows special characteristics of the weighting factors versus seismic intensity. The curves of A and B show the opposite characteristics and the curve of A would be the real one, and this characteristic will be verified by seismic damages to housings. Therefore the amendment is done about the weighting factors for the term of seismic intensity and finally Table-2 is recommended for computing quantitatively the antiseismicity of existing bridges.

ANTISEISMICITY OF BRIDGES AND CRITICAL VALUE USED FOR ESTIMATING PERCENTAGE OF COLLAPSED BRIDGES

Antiseismicity of bridges is usually defined by ratio of computed maximum strength of a bridge against erathquake loadings to assumed seismic forces acting to the bridge during earthquakes. In case of the new evaluation method, the weighting factors for the corresponding categories of the bridge to be examined will be picked up, and the total score for the bridge is obtained by multiplying the picked-up factors each by each, and it is concluded that the lower the total score, the higher the antiseismicity of the bridge to be investigated. According to the computation results obtained by applying the new evaluation method to 30 damaged bridges used as sample bridges for analysis of quantification analysis, the total scores of the heavily damaged bridges are not less than 30, and the total scores of arch type bridges are ranging between 6.7 and 7.3, which mean that arch-type bridges will reveal the good performance during severe earthquakes.

In the followings, the writer would like to discuss about the critical value for judging the seismic collapse of bridges. As mentioned above, 30 is the tentative critical value which is obtained after computing the total scores of the sample bridges and comparing the computed total scores with seismic damages to them. For checking the validity of the value of 30 as the critical score, the new method was applied to 260 bridges existing in Tokyo and compared real data on damage ratios (ratio of the number of damaged bridges to the total) of bridges in Tokyo in the event of Kanto earthquake with estimated damage ratios which are depending on the critical values. When the critical value becomes lower, the seismic damage ratio would be larger, because the intersection point of the cumulative curve shown in Fig.2 with the vertical line of the critical value goes down with the decrease of the critical value, and thus percentage of bridges whose total scores become more than the critical value, will increase up. This means that damage ratio of the bridges will be changeable with the critical value, but the real damage ratio of the structures inside an area should be definite, but not variable, when its average seismic intensity is given.

Average seismic intensity in Tokyo during Kanto earthquake 1923, was estimated as IX by modified Mercalli scale. The histograph of the total scores of 260 highways bridges in Tokyo is shown in Fig.3, under the estimated seismic intensity. If the critical value is 30, percentage of the severely damaged bridges is 4.6%, and if the former is 25, the latter is 8.1%, from the calculation results by the proposed method.

Total number of existing highway bridges in Tokyo was 1283 in case of Kanto earthquake, and 63 bridges among them were reported to be severely damaged in Okamoto's book[3]. The average damage ratio of bridges in Tokyo was about 5% from the above data. It is concluded from two results obtained by computing for 30 damaged bridges as well as by comparing reported damage ratio in Tokyo with computed values that 30 is reasonable as the critical value for evaluating antiseismicity of existing bridges, and this value is useful for discussion on seismic damage ratios of existing bridges which will be attacked by a strong earthquake, when the proposed simple method is used to obtain the total score of bridges.

RELATION BETWEEN SEISMIC DAMAGE RATIOS OF HIGHWAY BRIDGES AND TOTAL SCORES

When bridges whose total score is more than the critical value are estimated to be collapsed, and the cumulative curve as shown in Fig.2 is provided for the bridges in some area whose seismic intensity is assumed, seismic damage ratios of the bridges existing in the area mentioned above can be calculated by using the simple evaluation method proposed by the writer.

The case of seismic intensity IX has been already discussed in the previous section, and damage ratio of highway bridges in Tokyo will be 4.6%, by using the curve A-B-C in Fig.2. The total scores of the group of bridges which are evaluated by the point of A in case of seismic intensity of IX will be shifted to A' and A" due to the increase of seismic intensity of the area to X and XI, where the same group of bridges are existing. The group of bridges whose evaluation is shown by A, A' and A" is considered to be bridges with simply supported girders constructed on soft soil ground, because the total score of the group is slightly less than the critical value. Estimated damage ratios of bridges of this group for seismic intensities of X and XI are shown in Table-3. Total scores of bridges with the characteristic points of A, A' and A" will be shifted from 28 to 43 and 75 according to seismic intensity by which the bridges will be vibrated and the possibility of collapse is high in case of seismic intensity of X and very high for XI.

Bridges which are evaluated by point B for seismic intensity of IX are characterized, for example, as girder bridges of single span constructed on diluvial ground, because scores assigned for single span bridges and diluvial soil condition are not so high, and therefore the total score for bridges of this type will be the medium value.

The total scores of bridges characterized by points B, B' and B" are 15, 26 and 44 respectively according to the increase of seismic intensity from IX to XI. In this case, there is low possibility of collapse of girder bridges even though seismic intensity becomes X, but when seismic intensity is XI, there is high possibility of collapse of simply supported girder bridges of single span on diluvial ground. Total score of bridges mentioned above will be changed when the ground condition is changed from diluvial ground to rock ground. The total score of simply supported girder bridges of single span on rock ground is 22, because the weighting factor of rock ground is just the half of that for diluvial ground, and in this case the possibility of collapse will be not so high.

The type of bridges whose total score is about 7 as shown by point C in Fig.2 is considered as arch type bridge or rigid frame type bridge on alluvial or diluvial ground. The total score of bridges mentioned here is about 20, even when seismic intensity reaches to XI, and bridges of this kind will be safe in the event of severe earthquakes. However, if the ground condition of arch type bridges becomes very soft and there is very high possibility of liquefaction, the total score reaches to about 40, and it is concluded that there is high possibility of collapse of the bridges of this kind.

So far only qualitative analyses are done on the relationship between types of bridges and their collapse, because there is shortage of informations about stochastic data on ground conditions, height of bridge piers and kinds of supporting systems and so on. Total scores of bridges which have the same type of upper structures will have probabilistic distribution according to changes in ground conditions and other configulations.

Seismic damage ratios of highway bridges will be investigated by using assigned weighting factors in Table-2 and the critical value for judging degrees of seismic damages to bridges, when the necessary data on bridges related to all the category in Table-2 are given, and the number of bridges to be examined is as large as enough to stochastic analysis of the total scores of the bridges.

RELATIONSHIP BETWEEN DAMAGE RATIOS OF BRIDGES AND TYPES OF BRIDGES

Investigation reports on seismic damages due to Kanto earthquake 1923 and Niigata earthquake 1964[4] indicated that arch type bridges showed high antiseismicity and only slight damage occurred to Nihonbashi Bridge and Bandai Bridge.

If both the arch type bridge and the simply supported girder with piers of medium height are constructed on the same ground condition and subjected to ground shaking of the same seismic intensity, the total score of the former is less than the one of the latter, that is, the arch type bridge has higher antiseismicity than the simply supported girder, when the total scores of both bridges are calculated by the proposed simple method. This calculation result does not mean that the former is always in better performance than the latter during strong erathquakes, because the total score of the simply supported girder can be as small as the arch type bridge, if it is constructed on rock ground, and height of its piers is lower.

Generally speaking, number of damaged bridges in the event of one earthquake is not so many, and is not enough to be analyzed the relationship between antiseismicity of bridges and types of bridges, and therefore probabilistic analysis of damaged bridge due to earthquakes shows only qualitative trends of seismic damages related to the types of bridges, because each bridge is usually designed individually and behaviors of bridges of some type are dependent on soil conditions, construction materials, height of bridge piers and other conditions belonging to the bridges to be investigated. Substantially, it is not so easy for us to find the unique and deterministic solution on the relationship between damage ratios of bridges and types of bridges. It is concluded that useful data on damage ratio of bridges in the event of a certain earthquke will be the average damage ratio of bridges in strongly shaked area with some amount of area, as shown by Okamoto[3]. Of course, it is much desirable, if the relationship between damage ratios and types of bridges would be analyzed by good data obtained during and after the real earthquakes.

CONCLUSIONS

In this paper, the partial amendment of the new simple evaluation method for antiseismicity of bridges is mentioned and damage ratios of bridge shaked by earthqukes can be estimated by using the new method assuming that the critical value for judgement of possibility of severe damage to bridge is 30. The recommendable amount of the critical value has been discussed in this paper, but it has not been anthorized, and the definite value has to be confirmed through many results of other future investigations.

The caluculation results of some examples show that the new method including the weighting factors for each catergories of bridges is useful for estimating antiseismicity of bridges and possibility of collapse of bridges. However there remains some aspects to be investigated on accurracy of the computed total score. It is recommended that the new method is used for investigating antiseismicity of bridges as a first step and for screening the bridges to be analyzed more precisely.

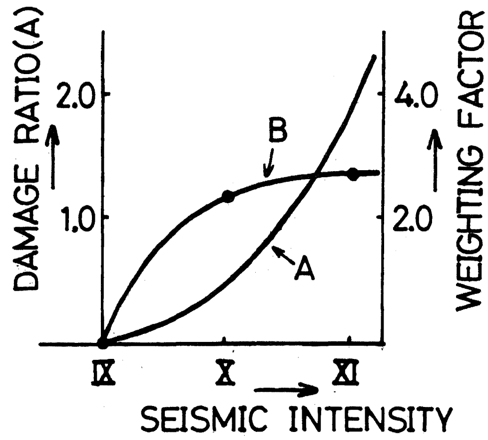

Fig.1 Relation between Seismic Intensity and Damage Ratio/Weighting Factor

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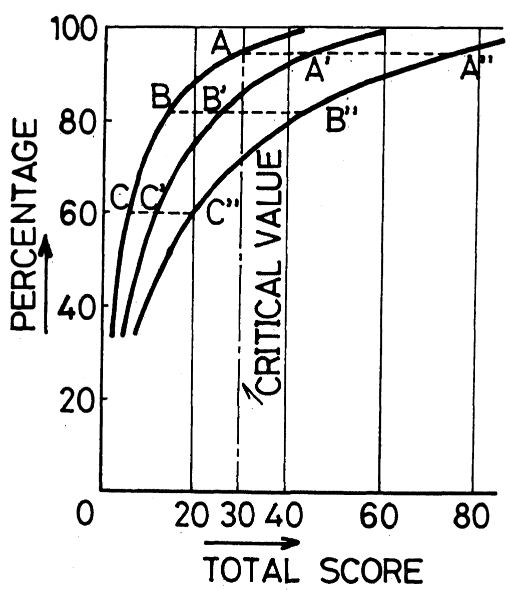

Fig.2 Cumulative Curves

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Table-1 Results of Quantification Analysis

Item	Category	Weighting Factor
Ground Condition	Diluvial Layer Alluvial Layer Soft Soil Layer	1.0 1.86 1.60
Liquefaction	Not Observed Observed	1.0 2.01
Type of Superstructure	Arch Simple or Cantilever	1.0 3.00
Type of Bearing	Ordinary Simple	1.0 1.15
Height of Pier or Abutment	Less than 5m Between 5 and 10m Greater than 10m	1.0 1.72 1.68
Number of Spans	One Two or More	1.0 1.75
Width of Pier Crest	Not Greater than 1.4m Greater than 1.4m	1.0 0.80
Seismic Intensity by MM Scale	IX X XI	1.0 2.41 2.64
Foundation	Pile Bent Pile Foundation Caisson	0.15 0.11 0.11

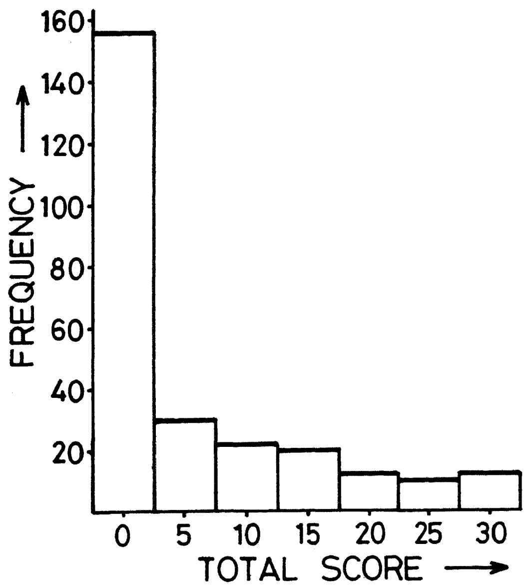

Fig.3 Number of Bridges versus Total Scores

Table-2 Proposed List of Weighting Factors(W.F.)

Item	Category	W.F.
Ground Condition	Rock Ground Diluvial Alluvial Soft and Thick	0.5 1.0 1.5 1.8
Liquefaction Potential	None Moderate High	1.0 1.5 2.0
Type of Superstruc.	Arch or Rigid Frame Continuous Simple or Cantilever	1.0 2.0 3.0
Type of Bearing	With Anti-seismic Devices Ordinary Simple	0.6 1.0 1.15
Height of Abutment or Pier	Less than 5m Between 5 and 10m Greater than 10m	1.0 Linear Interpolation 1.7
Number of Spans	One Two or More	1.0 1.75
Width of Pier Crest	Wide Narrow	0.8 1.2
Seismic Intensity	IX X XI	1.0 1.7 3.7
Foundation	Pile Bent Others	1.4 1.0
Material of Substructure	Masonry or Plain Concrete Others	1.4 1.0

Table-3 Relation between Seismic Intensity and Damage Ratios

Seismic Intensity	Damage Ratio
IX	4.6 %
X	13.1 %
XI	26.0 %