STUDY ON SAFETY DEGREE FOR EXISTING CONCRETE GIRDER BRIDGE MEMBERS BASED ON CALCULATED RELIABILITY

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ABSTRACT :

The gradation index of safety and reliability evaluation of in-service concrete girder bridge members is discussed based on the reliability theory and the existing safety evaluation methods. Modifying the reduction rate of loading capacity used in Code for Maintenance of Highway Bridges and Culvers, a new reliable index is presented in the same safety standard to reflect the relation between load and resistance. According to the basic principal of calibration method, a procedure is programmed with Matlab language to compute the recommended gradation index under various factors such as different load combinations, vehicle operating status and different failure modes. With these calculated numerical values, the calculated reliability indexes standard for the estimation of safety degree of in-service concrete girder bridge members is ultimately obtained.

KEYWORDS: existing concrete girder bridge, member, safety degree, reliability

1. INTRODUCTION

In China most of the bridges are concrete bridges, and lots of them are girder bridges. The general status of the bridges in our county is that a large scale of them is constructed at a comparatively low technique level. According to recent statistical report, a lot of bridges have safety problems and many other bridges belong to the third or fourth technical gradation, (According to Code for Maintenance of Highway Bridges and Culvert) which means these bridges also have potential safety problems. In assessing the safety of highway bridges, the evaluation criterion that based on limit state theory and design codes is promulgated successively in America, Britain, and Canada (AASHTO 1989; DOT 1993; CSA 1990). In China, however, the applicable codes and standards are *Code for Maintenance of Highway Bridges and Culvert* (JTG H11-2004) and *Identification Method of Bearing Capacity for Old Bridges* (try, 1988). The assessments are mainly based on bridge apparent situation or combined with calculation to analyze the technical condition and bearing capacity. The bridge safety reliability is not involved and system research of this kind is still lacked. To unify safety evaluation method and design theory which is based on probability-based limit state design method, a concrete bridge evaluate method and classification standard based on reliability theory is presented, which has high economic significance and important technology value (Liu Xi-la et al. 1994; Li Ya-dong 1997).

2. SAFETY EVALUATION METHODS OF CONCRETE GIRDER BRIDGE MEMBERS

Regarding to the technical grade of structural members, there is not a recognized standard as yet, particularly for the safety grading standards based on the reliability theory. Currently the methods to get safety evaluation grading indexes of in-service bridge members are mainly two types: the first is based on the reduction rate of loading capacity; and the second is based on the reduction rate of reliability indexes. In "*Standard for Appraiser of Reliability of Civil Buildings*"(GB 50202-1999) and "C*ode for Maintenance of Highway Bridges and Culvert*"(JTG H11-2004) the first method is adopted to calculate grading indexes.

However, the alternation of resistance is not the unique reason of structural security reduction, and bearing capacity reduction rate of structural members can not be used as an accuracy criterion in evaluating the security of bridge members. For that if the resistance reduction is to be used to evaluate the structural safety the load probability model adopted in design stage should be used in service time all the same and remain unchanged throughout the whole design base period. At the same time, the loading condition may be extremely different in different periods.

Therefore, the reduction rate of bearing capacity cannot reflect the numerical relation between resistance and load of structural members. It is rather one-sided to judge structure security only by the reduction rate of bearing capacity. The structure reliability is measured by reliability which is the statistic connection between load and resistance. There are two main methods based on the reliability theory to evaluate the bearing capacity: the first one is based on the design formula, the statistical law of member resistance is obtained from various parameters by using error transfer method.

The main problem of this method is that the correlation between the parameters is quite difficult to be determined from the existing statistical data. And it is also difficult to get a unified evaluation standard for different members, which is incompatible with the regulation of design code that different members have uniform objective reliability. In the second method, the evaluating indicator is first obtained with calibration method, and then measured values are substituted into design formula to calculate the reliable indicator of the actual structure. By comparing the actual reliability indexes with evaluating indicators, the grades of bridges are finally classified

In order to solve the problems mentioned above, calibration method is used to calculate the reliability indexes. In this paper, the loading capacity reduction rate is transformed to a reliable index in the same safety standard to reflect the relation between load and resistance. Based on this index, the assessment classification of structural members and the corresponding evaluation standard are presented as the safety valuation method for in-service bridge components (Wang You-zhi et al. 2002).

3. CALIBRATION METHOD FOR SAFETY EVALUATION GRADING STANDARD OF MEMBERS

During the calculation process of calibration method, the relation between load and resistance is linear as follows:

$$R_K = k_3 k_4 k_5 (k_1 S_{GK} + k_2 S_{QK}) \tag{3.1}$$

Where R_K is the nominal value of resistance; S_{GK} and S_{QK} are the nominal value effects of dead load and live load; k_1, k_2 are the separate coefficients of dead load effect and vehicular load effect; k_3 is the member service factor; k_4 is the separate coefficient of material performance, and k_5 is the regulation factor of k_2.

This relation can also be written by separate coefficients as follows:

$$(\gamma_G S_{GK} + \gamma_Q S_{QK}) = R_K / \gamma_R \tag{3.2}$$

where γ_R is the separate coefficients of resistance and changed with load fluctuation; γ_G, γ_Q are the separate coefficients of dead load effect and vehicular load effect , which related to load combinations. (Li Yang-hai et al. 1997).

So the statistic parameters of resistance can be obtained. Modifying these parameters the reliable indexes corresponding to the grades of members can also be obtained. On the premise that the probability distributions of three fundamental integrated variables remain unchanged, the measure of resistance reduction is performed by modifying the separate coefficients. Using these modified coefficients the reliable indexes and the bridge grades are calculated.

The division of bridge in *Code for Maintenance of Highway Bridges and Culvert* (JTG H11-2004) is bases on the reduction ratio of bearing capacity compared to the design value, which is equivalent to the reduction ratio of resistance. The classification according to the reduction ratio of bearing capacity is specified as follows:

The first type: Bearing capacity and driving conditions of bridge deck accord well with the design index;

The second type: Bearing capacity and driving conditions of bridge deck basically meet the design index;

The third type: the reduction ratio of bearing capacity is less than 10% compared to the design value, the driving condition of bridge deck is not very good;

The fourth type: the reduction ratio of bearing capacity is 10%~25% compared to the design value;

The fifth type: the reduction ratio of bearing capacity is above 25% compared to the design value.

According to the grading values mentioned above, the nominal value of resistance is reduced, the reliability index is calibrated, and the classifying reliable index is calculated. There is no definite limit between the former two types. Referring to "*Standard for Appraiser of Reliability of Civil Buildings*"(GB 50202-1999), the reduction ratio of 5% is taken for the grading limit of the first and second types.

In *Unified Standard for Reliability Design of Engineering Structures*(GB 50153-92), it is pointed out that structures or their members could no longer meet the security requirements when the reduction ratio of reliability index reaches 15%（$\beta^* < 0.85\beta_0$）.For this reason, the greater one of bearing capacity reduction ratio of 25% and the reliable index reduction ratio of 15% is used as the limit of the forth and fifth types.

In the process of determining the evaluation standard, the following factors are considered to calculate the classification indexes:

(1) Load combination states: major combination and additional combination;

(2) Operation states of automobile: general operation state and dense operation state;

(3) The proportion of automobile live load effect to dead load effect: 0.1, 0.25, 0.5, 1.0, 1.5, 2.5;

(4)Two different forced states: brittle failure and ductile failure which can be subdivided as axial compression, axial tension, bending, shearing（T and rectangular section）and large eccentric compression(short column).

According to the basic principal of calibration method, a procedure is programmed with Matlab language to compute the reliability indexes, which is shown in Fig.1.

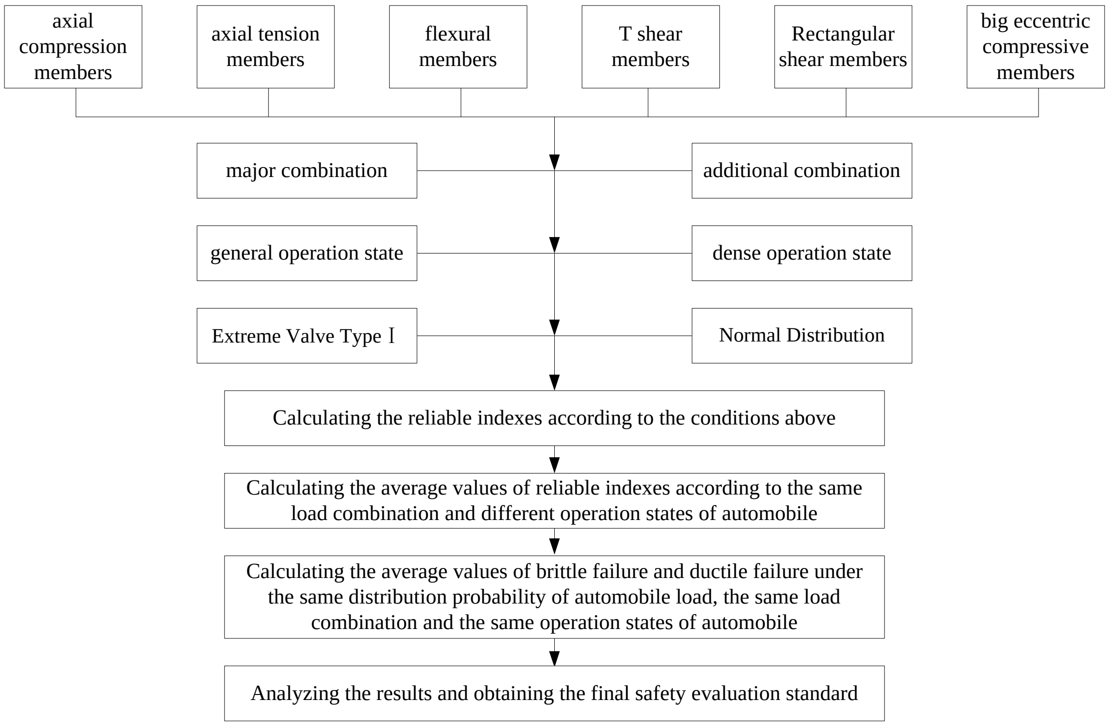

Figure 1 The flow process chart of calibration method

4. RESULTS OF CALIBRATION METHOD

4.1 The Average Reliability Indexes of Five Typical Members

The values of β under different ρ of five typical members are averaged firstly according to the same load combination and different operation states of automobile. Then the average values of β under general operation state and dense operation state are averaged again, the final results of average reliability indexes are shown in Table 1~ Table 3.

Table 1. The mean reliability indexes corresponding to the reduction rate of loading capacity (5%)

live load effects distribution probability	Combination of Action Effect	axial compression	axial tension	bending	large eccentric compression	shearing
Extreme Valve Type Ⅰ	major combination	5.3126	4.1595	4.7053	4.8063	4.7800
	additional combination	4.7078	3.7932	4.3927	4.0518	4.3642
Normal Distribution	major combination	5.4619	4.2417	4.8242	4.9256	4.7236
	additional combination	4.7879	3.4876	4.1107	4.2251	4.3714

Table 2. The mean reliability indexes corresponding to the reduction rate of loading capacity (10%)

live load effects distribution probability	Combination of Action Effect	axial compression	axial tension	bending	large eccentric compression	shearing
Extreme Valve Type Ⅰ	major combination	5.0613	3.8011	4.3772	4.4793	4.5724
	additional combination	4.3997	3.1020	3.7197	3.8388	4.1945
Normal Distribution	major combination	5.1204	3.8668	4.4714	4.5765	4.5866
	additional combination	4.4586	3.1122	3.7710	3.8763	4.1600

Table 3. The mean reliability indexes corresponding to the reduction rate of loading capacity (25%)

live load effects distribution probability	Combination of Action Effect	axial compression	axial tension	bending	large eccentric compression	shearing
Extreme Valve Type Ⅰ	major combination	3.9692	2.6027	3.2467	3.3810	3.8721
	additional combination	3.3455	1.8783	2.5747	2.7168	3.4543
Normal Distribution	major combination	4.0101	2.5997	3.2737	3.4019	3.8720
	additional combination	3.3506	1.8514	2.5607	2.7056	3.4458

4.2 The Synthetic Reliability Indexes of Five Typical Members

Based on the method above, the average values of brittle failure and ductile failure under the same distribution probability of automobile load, the same load combination and the same operation states of automobile are calculated, as shown in Table 4~ Table 6. As we know, the failure of large eccentric compression member is ductile failure. But in current codes, it is treated as brittle failure. To solve this contradiction, the values of large eccentric compression are not involved in Table 4~ Table 6.

Table 4. The synthetic reliability indexes corresponding to the reduction rate of loading capacity (5%)

live load effects distribution probability	Combination of Action Effect	automobile operation states	ductile failure	brittle failure	total average
Extreme Valve Type Ⅰ	major combination	general operation state	4.4139	5.0347	4.7243
		dense operation state	4.4508	5.0578	4.7543
		average	4.4324	5.0462	4.7393
	additional combination	general operation state	3.7751	4.5479	4.1615
		dense operation state	3.7351	4.5241	4.1296
		average	3.7551	4.5360	4.1455
Normal Distribution	major combination	general operation state	4.5794	5.1037	4.8416
		dense operation state	4.4864	5.0818	4.7841
		average	4.5329	5.0927	4.8128
	additional combination	general operation state	3.8648	4.6313	4.2480
		dense operation state	3.7333	4.5280	4.1306
		average	3.7990	4.5796	4.1893

Table 5. The synthetic reliability indexes corresponding to the reduction rate of loading capacity (10%)

live load effects distribution probability	Combination of Action Effect	automobile operation states	ductile failure	brittle failure	total average
Extreme Valve Type Ⅰ	major combination	general operation state	4.0847	4.8421	4.4634
		dense operation state	4.0936	4.7917	4.4426
		average	4.0891	4.8169	4.4530
	additional combination	general operation state	3.4495	4.3488	3.8992
		dense operation state	3.3722	4.2453	3.8087
		average	3.4108	4.2971	3.8539
Normal Distribution	major combination	general operation state	4.2245	4.9001	4.5623
		dense operation state	4.1137	4.8069	4.4603
		average	4.1691	4.8535	4.5113
	additional combination	general operation state	3.5075	4.3650	3.9362
		dense operation state	3.3757	4.2534	3.8145
		average	3.4416	4.3092	3.8754

Table 6. The synthetic reliability indexes corresponding to the reduction rate of loading capacity (25%)

live load effects distribution probability	Combination of Action Effect	automobile operation states	ductile failure	brittle failure	total average
Extreme Valve Type Ⅰ	major combination	general operation state	2.9866	3.9534	3.4700
		dense operation state	2.8628	3.8879	3.3754
		average	2.9247	3.9206	3.4227
	additional combination	general operation state	2.1273	3.3451	2.7362
		dense operation state	2.3257	3.4546	2.8902
		average	2.2265	3.3999	2.8132
Normal Distribution	major combination	general operation state	3.0219	4.0014	3.5116
		dense operation state	2.8514	3.8807	3.3661
		average	2.9367	3.9410	3.4388
	additional combination	general operation state	2.3110	3.4684	2.8897
		dense operation state	2.1011	3.3281	2.7146
		average	2.2060	3.3982	2.8021

It can be seen that the reliability indexes are basically higher than the target reliability indexes in codes of China when the reduction ratio of bearing capacity is 5%. According to “*Reliability and Probabilistic Limit State Design of Highway Bridge Structure*”(Li Yang-hai et al. 1997), it is because that the reliability index was reduced when determining the target reliability indexes, for the reliability indexes calculated by calibration method are much higher than the calibration results of the same members.

To solve this problem, the method is adopted as follows: firstly, comparing the calculated values with those listed in Table 4~ Table 6, the reduction rate of reliability indexes corresponding to the different reductions of bearing capacity is obtained. Then the reliability indexes for classifying bridge category could be calculated by multiplying the reduction rate with the target reliability indexes in the code, as shown in Table 7~ Table 8.

Table 7. The preliminary safety evaluation standard under main load combinations for bridge members of second-class highway

bridge category		The first type	the second type	the third type	the fourth type	the fifth type
reliability index β	brittle failure	≥ 4.7	≥ 4.46 <4.7	≥ 4.25 <4.45	≥ 3.45 <4.25	<3.45
	ductile failure	≥ 4.2	≥ 3.91 <4.2	≥ 3.60 <3.91	≥ 2.56 <3.60	<2.56

Table 8. The preliminary safety evaluation standard under additional load combinations for bridge members of second-class highway

bridge category		the first type	the second type	the third type	the fourth type	the fifth type
reliability index β	brittle failure	≥ 4.2	≥ 3.98 <4.2	≥ 3.76 <3.98	≥ 2.56 <3.76	<2.56
	ductile failure	≥ 3.7	≥ 3.39 <3.7	≥ 3.08 <3.39	≥ 1.99 <3.08	<1.99

And also, it has been mentioned earlier that structures and their members could not meet the security requirements when the ratio of reliability index reduced as 15% ($\beta^* < 0.85\beta_0$). By modifying the results above, the gradation index of safety and reliability evaluation of in-service concrete girder bridge members in ultimate limit state is obtained.

Table 9. The final safety evaluation standard under main load combinations for bridge members of second-class highway

bridge category		the first type	the second type	the third type	the fourth type	the fifth type
reliability index β	brittle failure	≥ 4.7	≥ 4.46 <4.7	≥ 4.25 <4.45	≥ 4.00 <4.25	<4.00
	ductile failure	≥ 4.2	≥ 3.91 <4.2	≥ 3.60 <3.91	≥ 3.57 <3.60	<3.57

Table 10. The final safety evaluation standard under additional load combinations for bridge members of second-class highway

bridge category		the first type	the second type	the third type	the fourth type	the fifth type
reliability index β	brittle failure	≥ 4.2	≥ 3.98 <4.2	≥ 3.76 <3.98	≥ 3.57 <3.76	<3.57
	ductile failure	≥ 3.7	≥ 3.39 <3.7	≥ 3.15 <3.39	<3.15	

4. CONCLUSIONS

Bridge assessment is the key point of the safety and smooth of the lines, is the foundation of the bridge maintenance, strengthening and technical transformation, and is the major element of bridge management. Modifying the reduction rate of loading capacity, a new reliable index is presented in the same safety standard to reflect the relation between load and resistance, which introduced probability method into the assessment of in-service concrete bridge members.

According to the basic principal of calibration method and the method proposed above, the calculated reliability indexes standard for the estimation of safety degree of second-class highway girder bridge members is obtained, which is consistent with the exiting standard. On the basis of the second-class calculated reliability indexes standard, the calculated reliability indexes standard of first-class and three-class highway girder bridge members can be obtained, which provides a quantitative applicable standard for the assessment of in-service concrete bridges and can be used in the identification of in-service concrete bridge members.

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