Analysis of Bearing Capacity of Highway Concrete Bridges

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Abstract. In order to ensure the safe operation of highway concrete bridges, this paper combines the appearance inspection and static load test to test and evaluate the bearing capacity of existing bridge structures, comprehensively judge the safety, reliability and durability of bridges, and maintain and reinforce bridges. The transformation provides technical reference and basis.

1. Introduction
With the continuous development of highway construction in China, the safety and durability of bridges have become increasingly prominent, and higher requirements have been put forward on the content and methods of bridge bearing capacity assessment and evaluation. In this paper, the actual bridge is taken as an example. According to the national norms such as design, maintenance and assessment, combined with the example, the bearing capacity of the existing concrete bridge structure is tested and evaluated through the appearance inspection and static load test.

1. Through bridge inspection and material testing, analyze the disease of each component of the upper and lower structure of the bridge, and determine the current condition and degree of deterioration of the bridge [1];
2. Through the static load test, the strain distribution law and corresponding deformation of the main force part under the load are measured, and the existing working state of the structure is grasped to judge whether the actual working condition of the bridge meets the design requirements or is in a normal stress state [2];
3. Finally, the appearance quality and the static load test are combined to test the current quality of the existing bridge structure, and the safety, reliability and durability of the bridge are comprehensively judged. The test results and conclusions can provide technical reference and basis for future maintenance and reinforcement.

2. Bridge detection method

2.1. Appearance detection method [3]
Appearance inspection is performed by visual observation combined with instrument observation:
1. The bridge deck mainly inspects the pavement, the smoothness of the bridge head, and the expansion joint;
2. The upper structure mainly checks the degree of concrete damage, the length, width, distribution and direction of the crack, and identifies the nature of the crack; identifies the honeycomb and pockmark of the concrete; records and marks the leaking area. Detect whether the bearing is aging, cracking, excessive shear deformation and void;
3. The lower structure detects the damage degree of the abutment concrete and the abutment crack. Observe whether the wing (ear) wall is cracked, tilted, slipped, sunken, and whether it has reduced or lost its ability to retain soil. Check the cone slope and slope protection for erosion, slippage, collapse, void, subsidence and other diseases. Check whether the structure is in good condition, whether the function is proper, whether the river bed is eroded or blocked by floating objects.

2.2. Non-destructive testing methods [2]
1. Crack detection
   Crack diseases are more common, and structural cracks are directly related to the bearing capacity and service life of the structure. The inspection is carried out according to the following principles:
   1) Whether the location and direction of the crack development exceed the allowable value of the specification;
   2) Whether there is a structural crack in the abutment or the cap that exceeds the allowable value of the specification: the structural crack of the foundation of the abutment and the position, direction, extension length and height of the corrosion crack of the steel.

2. Concrete strength testing
   The concrete strength is detected by the rebound method. The specific method is not described in detail in this paper. The rebound value takes the arithmetic mean of the remaining 10 after eliminating 3 maximum and 3 minimums, accurate to 0.1. When the concrete pouring side or the bottom surface is inspected in a non-horizontal state, the concrete surface or bottom surface is inspected in the horizontal direction, and the correction is carried out in accordance with the "Technical Regulations for Testing Concrete Compressive Strength by Rebound Method" (JGJ/T 23-2011). After the rebound value is measured, the carbonization depth value should be measured at a representative position.

3. Concrete carbonation depth detection
   After the rebound value is measured, the carbonization depth value is measured at a representative position. The detection principle is:
   1) The number of measurement areas is not less than 3, and the measurement area should be evenly arranged;
   2) The distance between the measuring hole and the corner of the component should be greater than 2.5 times the thickness of the protective layer;
   3) The number of measuring points should not be less than 30% of the number of measuring areas, and the average value is the carbonization depth value of each part of the component;
   4) The measured value of each hole is not less than 3, and the average value is taken, and each reading is accurate to 0.25 mm.

2.3. Static load test method
   The static load test is carried out by the test truck, so that the internal force or stress of the main control section and part of the structure is equivalent to the effect of the design load standard value, and the strain and deformation of the key parts are tested during the test, and the actual working condition of the structure is evaluated. And carrying capacity [4] [5].

1. Static load test purpose
   Through the investigation of the bridge condition and the static load test, the status quo of the bridge structure is understood, and the strength and rigidity of the bridge span structure are investigated to achieve the following objectives:
   1) Understand the status quo of the bridge and provide the basis for the bridge reinforcement design;
   2) Conduct a comprehensive inspection of the bridge, find the disease and analyze the extent of the impact of the disease on the safety and normal use of the bridge structure;
   3) Verify that the bearing capacity of the bridge span structure under the normal use load is designed to meet the design requirements;
   4) Investigate the actual working conditions of the bridge span structure and provide scientific basis for operation, maintenance and management.
In order to reduce the influence of temperature change on the static load test results, the static load test should preferably be carried out in a time period in which the temperature change does not exceed 2°C and the structural temperature tends to be stable.

2. Test loading principle

The test load efficiency \( \eta = \frac{S_{\text{stat}}}{S \times \delta} \) should satisfy: \( 0.95 < \eta \leq 1.05 \), where: \( S_{\text{stat}} \) is the calculated value of the displacement or force of the test part under the test load; \( S \) is the displacement of the design standard live load or the calculated value of force; \( \delta \) is the dynamic coefficient of the design.

In order to obtain the correlation curve between the structural test load and the displacement, and to prevent accidental damage to the structure, the test loading adopts the grading loading method, which is divided into 4-6 loading and 1 unloading. Each loading or unloading requires that the structural displacement be relatively stable during the previous load phase before entering the next loading phase. Generally, a sensitive measuring point is selected to be observed after loading, and it can be stabilized before entering the next level of loading. During the unloading process, it is forbidden to start multiple vehicles at the same time.

3. Test loading safety monitoring

The test load safety monitoring is to prevent the test load from causing damage to the bridge. The following conditions should be terminated halfway:

1) When the control point stress value reaches or exceeds the theoretically calculated control stress value;
2) When the control point displacement (or deflection) exceeds the allowable value of the specification;
3) Due to the length of the structural crack caused by the loading, the slit width is sharply increased, a large number of new cracks appear, and the crack width exceeding the allowable value is greatly increased, which has a great influence on the service life of the structure.

4. Data collection method

1) Concrete strain test: the vibrating wire strain gauge is used to arrange measuring points on the concrete surface;
2) Beam deflection test: The vertical displacement of the beam body is tested by a precision level gauge.

3. Case Analysis

A prestressed reinforced concrete hollow slab girder bridge has a span of 3-16m, the upper structure is 12 beams per span, and the lower structure is a column pier, a ribbed abutment, and a bored pile foundation; the support form is Ordinary plate rubber bearing; the bridge deck is arranged with a net width of 11.0m + 2 × 0.50m anti-collision wall; the bridge deck is provided with two MZL-80 expansion joints. The design load is car-20, trailer-100. The seismic intensity is 8 degrees.

3.1. Appearance inspection

Upon visual inspection, the bridge has the following diseases:

1. The upper structure of the first span of 9 joints is seepage and effluent; the second span of 11 joints is seepage and effluent; the third span of 10 joints is seepage and effluent. The support of the 2nd bridge of No. 2.0 has shear deformation and the deformation is 4mm; the 7th support of No. 2 pier has shear deformation, the deformation is 2–10mm, and there is local void in one support. The amount of void is 3mm. Surface water mark of No. 3.0 bridge, surface water mark of No.1 and No.2 cover beam; concrete rust swelling dew of No.1 cover beam right side, area 0.3m×0.25m; No.0 abutment slope stone masonry mortar falling off The No. 3 abutment slope was partially cracked. Filled in the expansion joints of No.4 and No.2; transverse cracks on the bridge deck of No.1 and No.2 piers, and pits on the top deck of No.1 pier, with an area of 2m×1.1m.
3.2. Material Testing

1. Concrete strength
Select the different types of components of the bridge to arrange the concrete rebound test area. The concrete rebounding area is 20cm×20cm square, 16 measuring points are tested in each measuring area, and 3 measuring areas are selected in every 10 rebounding areas to test the concrete carbonation depth. From the test results, the measured the evaluation scale of the components is "1".

2. Reinforced concrete cover thickness
Different types of members of the bridge are selected for thickness detection of reinforced concrete protective layer. From the test results, 7 of the component evaluation scales are "1", 1 component evaluation scale is "4", and 4 component evaluation scales are "5".

3. Concrete carbonization status
The different types of members of the bridge are selected to test the carbonation depth of the concrete. From the test results, the carbonization depth of the bridge is much smaller than the thickness of the protective layer of the steel, and the evaluation scale of the tested members is "1".

3.3. Static load test
Combined with the structural characteristics of the bridge and the environmental conditions, the 2nd span 0.5L maximum positive bending moment test was carried out.

3.3.1. Maximum positive bending moment test. 1. Test load arrangement, using four 450kN trucks for loading, the load effect and test efficiency are shown in Table 1, and the test load layout is shown in Figure 1 and 2.

| Load effect (strain) and test efficiency |
|-----------------------------------------|
| Maximum positive bending moment Highway-I (kN·m) | 349.9 | 349.9 |
| Load grading Level 1 Level 4 Level 3 Level 4 | Level 4 |
| Test load (kN·m) | 155.9 | 340.0 | 298.7 | 340.0 | 340.0 |
| Test efficiency | 0.45 | 0.97 | 0.86 | 0.97 | 0.97 |

Fig. 1 Schematic diagram of test load arrangement (right side load)
2. Strain test

Figures 3 and 4 show the strain distribution curves of the lateral beams at full load, and the strain values of the beams are the average values of the test strains. It can be seen from the data in the figure that the measured value of the strain at the bottom of each beam is less than the calculated value at full load, and the trend of the transverse strain curve of the measured strain is consistent with the trend of the calculated value curve.

![Strain transverse distribution curve](image-url)
Figures 5 and 6 show the deflection curves of the lateral beam bottoms at full load. It can be seen from the data in the figure that the measured value of the deflection of each beam bottom is less than the calculated value at full load, and the trend of the transverse deflection curve of the measured deflection is consistent with the trend of the calculated value curve.
4. Calibration coefficient evaluation

The check coefficient refers to the ratio of the measured value of the main measuring point to the corresponding theoretical calculated value: $\zeta = \frac{Se}{Ss}$. Under the same load, $\zeta < 1$ should be satisfied, which means that the actual condition of the bridge is better than the theoretical situation.

The maximum measured value of the main measuring point of the bridge is less than the calculated value, and the check coefficient is less than 1; the measured values of the main deflection measuring points are less than the calculated value, and the check coefficient is less than 1, both meet the specification requirements.

5. Residual strain (deformation) assessment

The relative residual displacement or residual strain $S_r$ is the ratio of the measured residual deformation or strain ($S_p$) to the measured total deformation or strain ($S_t$). The smaller the structure of $S_r$, the closer it is to the elastic working state, and the general requirement is $\leq 0.20$. The relative residuals of the main strain points of the bridge are less than 0.2, and the relative residuals of the deflection are less than 0.2, which meets the requirements of the specification, indicating that the beam is in an elastic working state.

6. Crack assessment

The crack width under the test load shall not exceed the allowable value specified in the "Testing and Evaluation Procedure for Bearing Capacity of Highway Bridges" (JTG/T J21-2011), and the crack closure width after unloading is less than 2/3 of the expanded width. No visible cracks were found near the test section during the test, and no numerical mutations occurred in the strain test results.

3.3.2. Fulcrum shear test (left side load). Loaded with 4 45t trucks. The maximum internal force and load efficiency of the control beam generated by loading at each level are shown in Table 2. The loading diagram is shown in Figure 7.

| Tab. 2 Shear force effect (bending moment) and load efficiency of Pier No. 2 |
|-----------------------------|-----------------------------|
| Working condition one       | Pivot shear                |
| Highway-Class I (kN)        | -43                        |
| Test load (kN)              | -43.7                      |
| Test efficiency             | 1.02                       |
For the fulcrum shear stress test condition, the strain is used to test the strain $\varepsilon_{0}$, $\varepsilon_{45}$, $\varepsilon_{90}$ in all directions, and the maximum shear stress $\tau_{\text{max}}$ is calculated from the measured strain value. At full load, the measured maximum shear stress and analytical values are shown in Table 3.

| Strain flower measured value ($\mu$e) | $\varepsilon_{0}$ | -1.1 |
|--------------------------------------|-------------------|------|
|                                      | $\varepsilon_{45}$| 3.6  |
|                                      | $\varepsilon_{90}$| 1.5  |
| Measured shear stress estimation value (MPa) | 0.098 |
| Shear stress theoretical analysis value (MPa) | 0.153 |

3.3.3. Summary. The static load test shows that the calibration coefficient of the main measuring points in each working condition is less than 1, which meets the requirements of the specification. The linear relationship between the measured value and the calculated value is good, and the relative residual is less than 0.2, which meets the requirements of the specification; the test section strain and deflection cross-bridge direction The measured value curve and the calculated value curve trend are basically consistent, and the measured value is less than the calculated value, no visible crack is found during the test.

4. Conclusion

With the continuous development of highway construction in China, a large number of old diseased bridges with structural degradation have been produced. The evaluation of bearing capacity involves many factors such as old bridge technology and degradation mechanism. The methods and standards involved in the test and evaluation of bridge bearing capacity cover a wide range and require a large amount of demand. The current testing methods mainly include design theory method, empirical method and dynamic static load test method. Among them, load test is the most direct and most commonly used method to evaluate the bearing capacity of bridge [6]. With the continuous advancement of science and technology, the road bridge bearing capacity detection and evaluation technology will develop in a scientific and standardized direction, providing important technical support for highway bridge maintenance management [7].

References
[1] JTG H11-2004, road bridge maintenance specification.
[2] JTG/T J21-2011, inspection and assessment procedures for bearing capacity of highway bridges.
[3] JTG/T H21-2011, the standard of assessment of highway bridge technology status.
[4] Zhang Lisha. Research on Bridge Structure Health Assessment Method Based on Static Load Test. Beijing: Beijing Institute of Technology, Vol. 5 (2015) No.42, p. 33-41.
[5] Xiang Hong, Yang Chunlin, Gong Jianglie. Discussion on the evaluation of bridge bearing capacity by static load test. Highway Engineering, Vol. 6 (2013) No.45, p. 217-219.
[6] Liu Rangwei. Discussion on the evaluation method of actual bearing capacity of overage service bridge. Highway Engineering, Vol. 2 (2019) No.15, p. 216-221.
[7] Zhang Xigang, Liu Gao, Ma Junhai, et al. Current status and prospects of bridge technology in China. Science Bulletin, Vol. 5 (2016) No.61, p. 415-425.