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Analysis of the Application of Static Load Test in Bridge Bearing Capacity Testing

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Abstract: This article uses real engineering projects as examples to analyze how static load test technology is applied in testing the bridge-bearing capacity. The analysis covers aspects such as testing section layout, test load and efficiency coefficient, loading plan, evaluation optimization, test result modification, and result evaluation. The aim is to support the accurate detection and evaluation of bridge-bearing capacity.

Keywords: Bridge engineering; Bearing capacity; Static load test; Loading plan; Test evaluation

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1. Introduction

Static load testing is an essential part of bearing capacity testing of bridge projects [1]. Therefore, this test should be done properly, with a reasonable layout of testing sections and setting of load and efficiency coefficients, and scientific formulation of loading plans. In this way, accurate static load test results can be obtained, thereby providing a reference for subsequent applications, operation, and maintenance of bridge projects [2].

2. Project overview

This study concerns an interchange ramp bridge project in a provincial road reconstruction and expansion project. The span combination of the bridge is (4*25) m + (4*25) m + (4*25) m+ (28 + 30 + 25) m; the overall structure is in the form of cast-in-place prestressed box beams. Its design driving speed is 40 km/h, its design load is highway level I, its design service life is 100 years, and its design seismic fortification intensity is seven degrees. To reasonably determine the bearing capacity of the bridge project, relevant units and staff performed static load tests. This article analyzes the application of static load tests in the bearing capacity evaluation of this bridge project and its results.

3. Static load test detection of bridge bearing capacity

3.1. Test section layout

A reasonable layout of testing sections is crucial in static load tests [3]. Therefore, in this project, the testers specifically used the actual stress characteristics of the bridge's test span structure to conduct static load tests on the side span and mid-span of the first continuous beam. **Table 1** shows the testing section and layout of testing items for the static load test of this bridge project.

Table 1. Test sections and layout of testing items

Serial number	Test section	Test items	Section description
1	Section 1-1	Deflection test and strain test	Maximum positive bending moment of side span
2	Section 1-2	Strain test	Maximum negative bending moment of the fulcrum
3	Section 1-3	Deflection test and strain test	Maximum positive bending moment at mid-span

3.2. Test load and efficiency coefficient

For existing bridge projects, the reasonable determination of test loads and efficiency coefficients is crucial in testing their bearing capacity through static load tests. The test unit used 4 three-axle trucks in the static load test of this project. The total weight of each truck was 45t, and the distance between its left and right wheels was 1.8 m. The distance is 3.5 m, and the distance between the front and rear wheels is 1.4 m. The main purpose of this static load test is to analyze the bridge's deformation when the engineering load is close to the expected value and the specific stress conditions of the main stress-bearing components [4]. Typically, the influence of the test load on the main section of the bridge structure should closely resemble the effect of the expected load value. The proximity of these effects was calculated using Equation 1.

$$\eta_q = \frac{S_s}{S(1+\mu)} \eta_q = \frac{S_s}{S(1+\mu)} \quad (1)$$

Among them, η_q μ_q represents the load efficiency coefficient during the static test; S_s represents the calculated internal force value of the bridge control section under the load during the static test; S represents the calculated value of the most unfavorable internal force formed by the bridge control section under the expected load; the impact coefficient is not included in this calculation; μ represents the impact coefficient applied according to the bridge engineering design specifications.

For this test, the design value of the bridge load corresponds to the highway level I load. In the theoretical calculation, test personnel primarily utilized the midas Civil 2019 bridge engineering calculation software to establish and compute the test joint model. **Table 2** shows the selection of efficiency coefficients in the static load test of the superstructure of this bridge project.

Table 2. Selection of efficiency coefficients

Serial number	Project	Test section		
		Section 1-1	Section 1-2	Section 1-3
1	Load design value	6196.4 kN·m	5230.5 kN·m	-3866.9 kN·m
2	Load test value	6135.8 kN·m	4975.0 kN·m	-3814.1 kN·m
3	Test efficiency coefficient	0.99	0.95	0.99

According to the relevant regulations on the static load test of the bridge project, the efficiency coefficient had to be controlled between 0.85 and 1.05. This test's efficiency coefficient was controlled between 0.95 and

0.99, which fully met the specification requirements.

3.3. Load scheme

After the test load and efficiency coefficient were determined, the loading plan was formulated based on the actual situation of the bridge engineering project and its actual load-carrying capacity test needs [5]. In this test, the load influence lines on each test section were first calculated using a software. The influence lines on each section were used to determine the load effect equivalence and the most unfavorable load layout principles. Then, the specific location for the loading vehicles were determined. The maximum positive bending moment test of the side span on Section 1-1 was regarded as the first test condition; the maximum positive bending moment test of the mid-span on Section 1-2 and the maximum negative bending moment test of the fulcrum on Section 1-3 were regarded as the second test condition. A cross-sectional diagram of the load vehicle layout under the off-load condition is drawn based on the test conditions and the actual vehicle load. Testers were loaded in four levels for each working condition, and each level was loaded sequentially in strict accordance with the designed vehicle position [6].

3.4. Evaluation optimization

After determining the loading plan and conducting the load test, the testing unit and staff optimized the overall test evaluation based on actual conditions. In the static load test of this bridge project, the tester primarily obtained the load-bearing capacity of the bridge project through structural calculation. This served as the basis for scientifically evaluating the results of the static load test [7]. After specific tests and evaluations, it was found that, in addition to some inherent factors in the tests, the evaluation results of the bridge's load-bearing capacity were also affected by its actual structural composition and characteristics. Consequently, when optimizing the load-bearing capacity assessment of bridge projects, testers also needed to avoid various influencing factors under their free attributes and characteristic conditions when calculating the bridge structure and, based on this, did a good corresponding test parameter correction work. In this way, the load-bearing capacity assessment of the overall bridge structure could be further optimized [8].

When the bridge section height and lateral connections were added to the bridge deck pavement layer, the pavement specifications influenced the bridge section parameters to varying degrees. Specifically, the cross-sectional moment of inertia experienced the most significant increase. According to the relevant design regulations of this bridge project, the concrete pavement on the bridge deck and the beam body exhibited a beneficial combination effect. Testers could account for the stress of the bridge deck during paving; however, it was necessary to deduct the wearing layer on the surface. Based on the actual situation of the bridge project, the thickness of the surface wear layer was controlled at 2 cm [9]. (2) Optimizing the bridge section reinforcement assessment: In theory, for bridge engineering structures without cracking issues, the gross section characteristics should be selected when evaluating the cross-section reinforcement. For bridge engineering structures with cracking problems, their geometric characteristics should be adjusted when evaluating the cross-section reinforcement. However, during the inspection of the bridge project, a certain deviation between the actual situation and the theoretical expectation was observed. Therefore, in the specific evaluation and optimization of load-bearing capacity, testers needed to use the existing load calculations as the basis and optimize the assessment of cross-section reinforcement using the following methods: (i) The actual elastic modulus of its main structure was calculated using the actual reinforcement ratio of the section. (ii) The actual moment of inertia of the cross-section was calculated based on the effect of the steel bars in the bridge structure. In this process, the bridge section reinforcement ratio was used as a key indicator to calculate the converted modulus of its reinforced concrete material (Equation 2).

$$\overline{E_a} = E_a(1 + \rho \frac{E_b - E_a}{E_a}) \quad (2)$$

Among them, the converted modulus of the reinforced concrete material in the bridge; E_a represents the elastic modulus of the concrete material itself in the bridge; E_b represents the elastic modulus of the steel material in the bridge structure; ρ represents the longitudinal reinforcement ratio of the reinforced concrete structure section of the bridge.

3.5. Result correction

After obtaining the corresponding static load test parameters, to ensure the accurate evaluation of the overall bridge engineering structure's bearing capacity, reflecting the actual conditions of the bridge [10]. The test results were corrected using several strategies.

The first strategy is the calibration coefficient. The testers mainly combined the actual design regulations of the bridge engineering project to scientifically compare the obtained test detection values and analytical values and use them as the basis for evaluating the mechanical performance of the overall bridge structure. The calibration coefficient was mainly calculated using Equation 3.

$$\delta = \frac{S_e}{S_s} \quad (3)$$

Among them, the calibration coefficient represents the actual measured strain value or elastic displacement value of the main detection point of the bridge structure under the test load condition and S_s represents the theoretical strain or displacement of the main detection point's position under the test load condition. In specific test testing, only when $\delta \leq 1$ does it mean that the actual bearing capacity of the bridge project meets the engineering design standards.

The second strategy was temperature effect correction, which was calculated using Equation 4.

$$S = S' - \Delta_t \cdot K_t \quad (4)$$

Among them, S represents the change in the static load loading measurement of after temperature correction; S' represents the static load loading measurement of the detection point before temperature correction; Δ_t represents the temperature of the measurement point during the observation period of S' and the strain detection should select the surface temperature, and the air temperature should be selected when detecting deflection; K_t represents the change parameter of the measured value for every one °C increase in temperature at the detection point under no-load conditions.

Subsequently, each detection point position's displacement and strain was calculated using Equations 5–7.

$$S_t = S_1 - S_i \quad (5)$$

$$S_e = S_1 - S_u \quad (6)$$

$$S_p = S_t - S_e = S_u - S_i \quad (7)$$

Among them, S_t represents the total strain; S_1 represents the strain measurement value when loading to the steady state; S_i represents the strain measurement value before loading; S_e represents the elastic strain; S_u represents the strain measurement value when unloading to the steady state; S_p stands for participation strain.

During this process, the concept of relative residual displacement was introduced to evaluate the extent to which the bridge engineering structure has entered the plastic working state locally or as a whole. The relative residual strain or displacement was calculated using Equation (8).

$$S_p' = \frac{S_p}{S_t} \cdot 100\% \quad (8)$$

Among them is the relative residual strain or displacement value.

3.6 Evaluation of test results

After conducting the static load test and result correction, the results were evaluated according to two test conditions for the evaluation of its bearing capacity.

Under the first test condition, the maximum strain verification coefficient and deflection verification coefficient of the continuous beam structure participating in the test were 0.82, both less than 1, indicating that its bearing capacity meets the actual design of the bridge project standard. The maximum value of the relative residual strain was 9.2%, which was lower than the maximum allowable value of residual strain (20%) in this bridge project. The maximum relative residual displacement was 2.8%, which was lower than the maximum allowable value of residual strain in this bridge project (20%). Thus, under the first test condition, the bridge engineering structure's actual load-bearing capacity fully complies with its engineering design standards.

Under the second test condition, the continuous beam structure's maximum strain verification coefficient was 0.79, and the deflection verification coefficient was 0.82, both below 1, indicating compliance with the bridge project's design standards. The maximum relative residual strain was 5.8%, below the project's allowable value of 20%. Additionally, the maximum relative residual displacement was 3.2%, also below the project's allowable value of 20%. Hence, under the second test condition, the bridge engineering structure's actual load-bearing capacity fully meets its engineering design standards.

4. Conclusion

The static load test plays a crucial role in assessing the bearing capacity of modern bridge structures. To ensure accurate evaluations, testing units and personnel must adhere to specific design standards, employ suitable methods, and implement appropriate measures during on-site static load testing. By making necessary corrections to the test results, the overall bearing capacity of the bridge structure can be scientifically and precisely evaluated. This provides valuable insights for its subsequent operation, maintenance, and application, ultimately enhancing the quality of load-bearing capacity testing and ensuring optimal performance and service life of modern bridge structures.

Disclosure statement

The authors declare no conflict of interest.

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