Static and dynamic load test on concrete hollow-core slab bridge

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Abstract. In this paper, dynamic and static load test were carried out on a multi-span reinforced concrete simply supported hollow core slab bridge in Shenyang, Liaoning Province. Through the static load test, the quality and reliability of the project are evaluated, and the results show that under the action of 0.88 times of highway-class I load, the deflection and strain check coefficients of the control section of the tested condition are less than 1, which meets the specification requirements, and the measured relative residual deformation and relative residual strain are less than 20%, and the bridge structure is basically in the elastic working state. And combined with the finite element analysis model, the comparison between measured data and calculated data is carried out. Through the dynamic load test, the self-oscillation frequency and damping ratio of the superstructure were tested, and the results showed that the measured damping ratio was 0.690%, the first-order measured vibration pattern conformed to the variation rule of the vibration pattern of the simply supported girder bridge, and the measured self-oscillation frequency was 13.594 Hz, and the measured self-oscillation frequency (fundamental frequency) was greater than the calculated frequency, and the structural actual stiffness was greater than the theoretical stiffness, and the working condition was good. This study is of great significance for the assessment of bearing capacity and quality control of concrete hollow core slab bridge, and provides a useful reference for bridge design and operation.

Keywords: dynamic load test; static load test; bearing capacity; concrete hollow core slab; finite element analysis.

1. Introduction

As an important component of modern transportation infrastructure, the safety performance of highway bridges has received widespread attention. In the process of bridge design, construction and operation, static and dynamic load test are key steps in evaluating the structural performance of bridges[1]. By conducting static and dynamic load test on bridges, the response characteristics of bridges under actual operational loads can be revealed, providing a scientific basis for ensuring bridge safety and extending service life [2,3]. The static load test is mainly used to evaluate the force performance of the bridge under fixed load, and combined with the finite element model to do scientific analysis [4,5]. The static load test can adopt the principle of equivalent internal force, which is to use the principle of equivalent internal force generated by equivalent load in the test section and the principle of equivalent internal force generated by control load in the test section to conduct static load test on the loaded bridge span [6, 7]. The dynamic load test simulates the actual situation under dynamic loads such as vehicle travelling, and through the real bridge test of structural intrinsic modal parameters, it can understand the dynamic characteristics of the bridge span structure (e.g., self-oscillation frequency, damping coefficient, vibration mode, etc.), evaluate the working condition of the bridge, which can verify or modify the theoretical calculated values and serve as the basis of structural design, and provide the necessary data and information for the operation and maintenance management of the bridge in the future [8]. The aim of this paper is to carry out systematic dynamic static load test on bridge to assess the safety and reliability of the project.
2. Project background

The bridge is located in Shenyang City, Liaoning Province, and the bridge was completed in November 2023, as shown in Figure 1 (a) and (b). The total length of the bridge is 197 m, the intersection angle is 90°, the span combination is 17×11.38 m, and the total length of the span is 193.46 m. The superstructure is reinforced concrete simply supported hollow slab, 11 slabs per hole, and the width of the slabs is 1.5m; the substructure is four-pillar piers and abutments. The clear width of bridge deck is 11.5m, the left side is set up with concrete parapet width 0.5m, and the right side is set up with pavement width 5.0m. The bridge elevation and plan diagram are shown in Figure 1 (c), and the bridge superstructure cross-section diagram is shown in Figure 1 (d).
3. Test content

3.1 static load test

(1) Layout of measurement points
According to the internal force envelope diagram and stress distribution of the bridge structure, combined with the principle of the most unfavourable stress of the bridge structure, the test condition is determined as the maximum positive moment of the cross-section in the span of the 16th hole. The deflection measurement points are arranged at the pivot point and the centre of the bottom of the slab in the middle of the span, as shown in Figure 2 (a). The strain measurement point is arranged at the bottom span centre, as shown in Figure 2 (b).

(2) Determination of load
The loading process of the load test adopts the principle of 3-level increment, and the working condition loading is 3-level loading: the first level loading is to pre-load one vehicle on the bridge span to eliminate non-elastic deformation; Load 2 vehicles at the second level and 3 vehicles at the third level, and observe the changes in various control parameters under each level of load at any time. The duration of each loading and unloading depends on the time required for the structural displacement to reach a stable standard. The loading site diagram of heavy-duty vehicles is shown in Figure 3, and the schematic diagram of loading vehicles is shown in Figure 4. The load arrangement for the tested working conditions is that the lateral loading is carried out using left side offset loading, and the longitudinal loading is carried out using three-axis standard vehicle loading, with the loading vehicle's axis aligned with the mid span. According to the “Load Test Methods for Highway Bridge” (JTG/T J21-01-2015), the static load test load is calculated, and the efficiency calculation table of the static load test load is shown in Table 1.

<table>
<thead>
<tr>
<th>Project</th>
<th>Loading conditions</th>
<th>Maximum positive bending moment of the mid span section of the 16th hole edge beam (operating condition)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design bending moment (kN. m) (Highway - Class I)</td>
<td></td>
<td>536</td>
</tr>
<tr>
<td>Loading bending moment (kN. m)</td>
<td></td>
<td>473</td>
</tr>
<tr>
<td>Static load test efficiency η</td>
<td></td>
<td>0.88</td>
</tr>
</tbody>
</table>
(3) Finite element analysis

Use finite element software to simulate the bridge structure and establish a spatial calculation model, calculate the deflection and strain values of the bridge structure under working conditions, and compare them with experimental data, as shown in Figure 5.

3.2 Dynamic load test

The dynamic load test adopts the environmental random excitation method, and uses vibration sensors to measure relevant mechanical data such as displacement, acceleration, and velocity. Apply spectral analysis and other methods to study the natural vibration characteristics (frequency, mode shape, damping ratio) of the longitudinal bending of the upper structure of the bridge in the vertical plane under dynamic loads. Due to the significant environmental impact and interference with data results, dynamic load testing is an effective method for qualitative analysis of bridge and a supplement to static load testing. The vibration sensor measurement point for this experiment is arranged at the mid span position of the 16th hole.

4. Test results and analyses

4.1 Static load test results

(1) Strain test results

Under the action of the third level test load, the strain values of each control section of the 16th hollow slab were tested, and the measured values were compared with the theoretical values as
shown in Figure 6. According to Figure 6, the measured total strain value under load is smaller than the theoretical strain value. The relationship curve between the load and the measured strain values of the main control sections of plates 16-11 under experimental load is shown in Figure 7. From Figure 7, it can be seen that under the test load, the load strain relationship of plates 16-11 is close to a linear relationship, indicating that the structure is close to an elastic working state.

![Fig. 6 Comparison chart between measured total strain and theoretical strain values](image1)

The relative residual strains and effectiveness coefficients for the mid-span section of the 16th hole hollow core slab are shown in Table 2.

![Fig. 7 Load-Strain curve](image2)

<table>
<thead>
<tr>
<th>Hollow slab number</th>
<th>No.1</th>
<th>No.2</th>
<th>No.3</th>
<th>No.4</th>
<th>No.5</th>
<th>No.6</th>
<th>No.7</th>
<th>No.8</th>
<th>No.9</th>
<th>No.10</th>
<th>No.11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verification coefficient</td>
<td>0.34</td>
<td>0.37</td>
<td>0.32</td>
<td>0.31</td>
<td>0.32</td>
<td>0.38</td>
<td>0.37</td>
<td>0.43</td>
<td>0.39</td>
<td>0.42</td>
<td>0.44</td>
</tr>
</tbody>
</table>

According to Table 2, under the action of 0.88 times the highway level I load, the strain calibration coefficient of the measurement point of the cross-section in the span of the 16th hole hollow plate is 0.31 ~ 0.44, the calibration coefficient is less than 1, which meets the requirements of the “Specification for Inspection and evaluation of load-bearing capacity of highway bridges (JTG/T J21-2011)”; the relative residual deformation is 2.56% ~ 19.13%, which is less than 20%, indicating that the structure is basically in the elastic working condition.

(2) Deflection test results

The comparison between the measured and theoretical deflection values of the mid span section of the 16th hole hollow slab under the action of the third level test load is shown in Figure 8. As shown in Figure 8, the measured total displacement is much smaller than the theoretical deflection value. The relationship curve between the load and the measured deflection values of the main control sections of plates 16-11 under the experimental load is shown in Figure 9. From Figure 9, it can be seen that under the test load, the load strain relationship of plates 16-11 is close to a linear relationship, indicating that the structure is close to an elastic working state.
The relative residual strain and verification coefficient of the mid span section of the 16th hollow slab are shown in Table 3.

<table>
<thead>
<tr>
<th>Hollow slab number</th>
<th>No.1</th>
<th>No.2</th>
<th>No.3</th>
<th>No.4</th>
<th>No.5</th>
<th>No.6</th>
<th>No.7</th>
<th>No.8</th>
<th>No.9</th>
<th>No.10</th>
<th>No.11</th>
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<tbody>
<tr>
<td>Relative residual strain</td>
<td>4.24</td>
<td>2.00</td>
<td>3.76</td>
<td>3.82</td>
<td>3.41</td>
<td>1.20</td>
<td>1.26</td>
<td>1.51</td>
<td>1.75</td>
<td>1.58</td>
<td>1.30</td>
</tr>
<tr>
<td>Verification coefficient</td>
<td>0.34</td>
<td>0.37</td>
<td>0.37</td>
<td>0.36</td>
<td>0.38</td>
<td>0.37</td>
<td>0.35</td>
<td>0.34</td>
<td>0.39</td>
<td>0.39</td>
<td>0.37</td>
</tr>
</tbody>
</table>

According to Table 3, under the action of 0.88 times the highway level I load, the deflection calibration coefficient of the 16th hole hollow plate measurement point is 0.34 ~ 0.41, the calibration coefficient is less than 1, which meets the requirements of the “Specification for Inspection and Evaluation of load-bearing capacity of highway bridges (JTG/T J21-2011)”; the relative residual deformation is 1.07% ~ 5.10% respectively, which is less than 20%, indicating that the structure is basically in the elastic working condition.

(3) Horizontal distribution coefficient test results

Through the 3rd level test load under the action of the 16th hole of the measured deflection value of each beam plate, the calculation of the actual lateral distribution coefficient of each beam plate, and with the theoretical lateral distribution coefficient comparison curve shown in Figure 10. Figure 10 shows that the measured lateral distribution coefficients are close to the theoretical lateral distribution coefficients, and the change rule of the two data is basically the same, but there is also an error in the data, which is less than 8%, indicating that the finite element software effectively simulates the structure of the girder bridge.
4.2 Dynamic load test results

Through this dynamic load test, it is known that the measured natural frequency (fundamental frequency) of the superstructure of the bridge is greater than the calculated frequency, the actual stiffness of the structure is greater than the theoretical stiffness, and the working condition is good. The natural frequency test results of the superstructure are shown in Table 4, and the measured frequency domain diagram of the hollow slab is shown in Figure 11.

Table 4. Table of natural frequency test results for superstructure

<table>
<thead>
<tr>
<th>Position</th>
<th>Fundamental frequency(Hz)</th>
<th>Damping ratio(%)</th>
<th>Frequency ratio ①/②</th>
</tr>
</thead>
<tbody>
<tr>
<td>16th hole hollow slab</td>
<td>13.594</td>
<td>7.579</td>
<td>0.690</td>
</tr>
</tbody>
</table>

5. Conclusion

This article provides a qualitative and quantitative evaluation of a multi-span reinforced concrete simply supported hollow slab bridge in Shenyang, Liaoning Province. The following conclusion can be drawn.

(1) The 16th hole hollow slab tested, under the action of 0.88 times the highway level I load, has a deflection and strain verification coefficient of less than 1 for the control section under test conditions, meeting the requirements of the specifications.

(2) The tested 16th hole hollow slab, under the action of 0.88 times the highway level I load, has a relative residual deformation and relative residual strain of less than 20%, and the bridge structure is basically in an elastic working state.

(3) The tested 16th hole hollow slab has a measured damping ratio of 0.690%, and the first-order measured vibration mode conforms to the variation law of the simply supported beam bridge vibration mode. The measured natural frequencies are 13.594Hz, and the measured natural frequency (fundamental frequency) is greater than the calculated frequency. The actual stiffness of the structure is greater than the theoretical stiffness, and the working condition of the bridge beam is good.
Acknowledgments

The authors acknowledge the financial support provided by fundamental scientific research expenses at Heilongjiang Provincial College and University (2022-KYYWF-1094) and Heilongjiang Province Ecological Environment Protection Research Project (HST2023GF004).

References


