Dynamic and Static Load Test of PC Composite Box Girder Bridge with Corrugated Steel Web

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Abstract: In order to evaluate the safety of a PC composite box girder bridge with corrugated steel webs, Midas/Civil is used to analyze the bridge. Through dynamic and static load tests, the actual working state, vibration characteristics and dynamic response of the bridge under load are understood. Combined with experimental research and theoretical analysis, the comprehensive evaluation of the bearing capacity and working condition of the bridge is made, which provides reference for the design and maintenance of such bridges.

1. Introduction
In recent years, with the continuous expansion of bridge construction scale, PC composite box girder structure with corrugated steel webs has been rapidly developed and applied for its advantages of light weight and short construction period [1]. In order to further understand the mechanical characteristics of this kind of structure, an experimental study on PC composite box girder bridge with corrugated steel webs is carried out, and the mechanical properties of this structure are analyzed theoretically and experimentally, which provides data reference for similar bridge construction.

2. General situation of Engineering
The superstructure of an elevated bridge is composed of two PC composite box girders with corrugated steel webs of equal height. The span of the bridge is 9*50m+9*50m+40m. The steel webs are arranged in double-width with symmetrical cross-sections of left and right. There are 20mm partitions between the two. The single-width section is inclined webs of single box and single chamber. The width of the roof is 12.75m, the width of the bottom is 6.0m, and the inclination angle of the webs is 75 degrees. The top edge of a single section adopts a one-way 2% transverse slope, the horizontal main line waveform arrangement at the bottom of the beam, the beam height at the center line of the box chamber is 3.5m, the cantilever length of the top plate of the box girder is 3.2m, the width of the room is 6.35m, the rear end of the cantilever of the top plate is 0.2m, and the thickness of the root is 0.55m. C60 high strength concrete is used for the top and bottom slabs of the main girder, and Q345qC steel is used for the steel webs. The web of corrugated steel adopts BCSW1600 type, and the thickness of steel plate adopts 20mm and 24mm two specifications. The permanent prestressing of the main girder is composed of internal and external prestressing. The design technical standard is 100 years of design reference period, design safety grade 1, environmental class I, load grade city-A, basic seismic intensity 7 degrees, peak acceleration of ground motion 0.15g, design speed 80 km/h, bridge cross slope 2%.
3. Test scheme

3.1. Test Loading Design

3.1.1. Determination of test conditions. According to the actual situation of the bridge, the following tests are carried out in this test:

1. The maximum positive moment effect of the first span 0.46L section is loaded, which is divided into symmetrical loading and right side bias loading, i.e. working conditions 1 and 2;
2. The maximum negative moment effect loading condition of the box girder section near the fulcrum of 0YP2 pier is condition 3.
3. The maximum positive moment effect loading of the middle section of the second span is divided into symmetrical loading and right side bias loading, i.e. working conditions 4 and 5.
4. The second span 1/4L section is loaded with the maximum positive moment effect, which is divided into symmetrical loading and right side bias loading, i.e. working conditions 6 and 7.

3.1.2. Selection of test section. Combining with the actual situation of the bridge, the bridge structure analysis software Midas/Civil is used to calculate and analyze the bridge structure. According to the internal force envelope diagram of the main bridge under live load (considering impact), as shown in Figure 1, 1-1, 2-2, 3-3, 4-4 sections are selected as test control sections for deflection and stress test [2], as shown in Figure 2.

![Bending moment envelope diagram of main bridge under live load (kN.m)](image)

Figure 1 Bending moment envelope diagram of main bridge under live load (kN.m)

![Diagram of test section position of box girder](image)

Figure 2 Diagram of test section position of box girder

3.2. Content and method of experiment

3.2.1. Static Load Test. The static load test mainly tests the stress and deflection of the loading section. The purpose is to test the deformation of the bridge structure under load and the stress state of the main stress components [3]. The test was carried out by six rear eight-wheeled vehicles, which were numbered 1-6 according to the weight of 434.4KN, 403.8KN, 434.4KN, 364.3KN, 385.5KN and 448.5KN respectively. Seven working conditions were determined according to the test plan, as shown in Fig. 3-9. Before the formal loading test, two test heavy vehicles were used to preload the loaded bridge respectively. According to the most unfavorable structural characteristics, preloading was carried out. The loads stop symmetrically in the middle of the test span, near the fulcrum and in the middle of the adjacent span, with each section remaining for 30 minutes. Formal loading test requires graded loading. Each main loading condition requires repetition, but the repeated loading condition does not carry out graded loading. Before each loading condition, the vehicle load on the bridge must drive away from the bridge [4]. Loading is carried out according to No. 1 to No. 6 vehicles in turn, unloading is carried out according to No. 6 to No. 1 vehicles in turn. When loading and unloading, stable reading and zero reading are required for each working condition.
Fig 3. Schematic Chart of Vehicle Loading under Working Condition 1

Fig 4. Schematic Chart of Vehicle Loading under Working Condition 2

Fig 5. Schematic Chart of Vehicle Loading under Working Condition 3

Fig 6. Schematic Chart of Vehicle Loading under Working Condition 4

Fig 7. Schematic Chart of Vehicle Loading under Working Condition 5
3.2.2. Dynamic Load Test. Based on the moment envelope diagram of the bridge structure, the position of the maximum structural strain in the second span under live load is obtained. Therefore, the experimental observation section is located in the middle of the second span, and two dynamic displacement meters are arranged in the section. Vehicle excitation test is carried out under the same static load test. During the test, a loading vehicle is tested under seven working conditions. The loading vehicle passes through the bridge structure at a uniform speed of 10-70 km/h. Because of the impact on the bridge deck during the driving process, the bridge structure will vibrate [5]. The dynamic deflection and dynamic strain time history curves at the test section are measured by the dynamic testing system to measure the amplitude response and dynamic strain under the condition of driving. In the absence of any traffic loads on the bridge deck and irregular vibration sources near the bridge site, the micro-amplitude vibration response of the bridge span structure caused by random load excitation at the bridge site is measured by vibration picker. The dynamic characteristics of the structure, such as the natural frequency and damping ratio, are measured. Acceleration sensors are transversely arranged on both sides of the bridge deck and the longitudinal measuring points are measured. The layout is shown in Figure 10.
4. Test results

4.1 Analysis of Static Load Test Results

4.1.1 Analysis of deflection measured data. The measured and calculated results of each span deflection under each working condition are as follows: the maximum value of measured deflection in working condition 1 is 5.633 mm, the maximum value of calculated deflection is 9.910 mm, the maximum value of measured deflection in working condition 2 is 6.436 mm, the maximum value of calculated deflection is 9.958 mm, the maximum value of measured deflection in working condition 4 is 5.419 mm, and the maximum value of calculated deflection in working condition 5 is 8.830 mm. The maximum value of measured deflection in working condition 6 is 3.649 mm, the maximum calculated value is 8.878 mm, the maximum measured deflection of working condition 7 is 3.991 mm, and the maximum calculated value is 5.993 mm. The measured deflection of each working condition is less than the theoretical deflection, and the maximum deflection is much less than the stipulation of L/600 in the code; the deflection check coefficient is 0. The stiffness of the bridge is less than 1 between 41 and 0.67, which indicates that the bridge has enough stiffness to meet the normal use requirements of the design load.

4.1.2 Analysis of strain measured data. Comparing the measured and calculated strain values of each span under different working conditions, it is found that the strain calibration coefficients of test sections are between 0.29 and 0.99, and the measured strains do not exceed the calculated strains, which meets the requirement that the strain calibration coefficients of highway bridge bearing capacity test and evaluation regulations (JTG/T J21-2011) are less than 1. The relative residual strain of the test section is between 0.5% and 8.8%, which meets the requirements of the code. It can be seen that the test span of the bridge can basically restore to its initial state after being subjected to force, and it is in an elastic working state, which shows that the main girder structure has sufficient strength.

4.2 Analysis of Dynamic Load Test Results

4.2.1 Natural frequency. The measured value of first-order vertical vibration frequency of the box girder of the first and second span of the Viaduct under load is 3.20 Hz. As shown in Fig. 11-13, the theoretical value is 2.91 Hz, and the measured value is 1.10 times of the theoretical value. It shows that the vertical dynamic stiffness of the box girder bridges of the first and second span of the viaduct is good and meets the requirements of the code.

![Fig 11. Natural Vibration Frequency of 0.46L Measured Point of the First Span Box Girder](image-url)
4.2.2 Damping Ratio and Impact Coefficient. Damping ratio analysis is carried out at 0.46L measuring point of the first span box girder, 1/4L measuring point of the second span box girder and 1/2L measuring point of the second span box girder. It is concluded that the damping ratio of the first span and the second span box girder of the bridge is between 3.40% and 3.78%. Based on the results of dynamic displacement test of the bridge and the calculation method of impact coefficient of the bridge under the sports car test, the driving of the bridge in a loading vehicle is obtained. Under the test, the impact coefficient is 0.02, 0.02, 0.02, 0.02, 0.08, 0.07, 0.11 and 0.08 when the vehicle speed is 10, 20, 30, 40, 50, 60 and 70 km/h, respectively. The maximum impact coefficient of the bridge is 0.11, which is smaller than the calculation result of the General Code for Design of Highway Bridges and Culverts (JTG D60-2004), indicating that the bridge is in normal working condition and the driving condition is good.

5. Conclusion

5.1. The measured deflection and strain of the main girder under each working condition are less than the theoretical value, and the maximum measured deflection is far less than the L/600 stipulated in the
code, and the relative residual strain is between 0.5% and 8.8%. This shows that the bridge is in elastic working state, and the main girder structure has sufficient stiffness and strength, which can meet the normal use requirements of the design load.

5.2. The measured damping ratio of the bridge is 3.4-3.78%, the measured natural frequency is 1.1 times of the theoretical calculation value, and the maximum impact coefficient is 0.11. This shows that the ability of dissipating external energy of the bridge is normal, the overall dynamic stiffness and driving conditions of the bridge are good, and the safety of the bridge structure can be guaranteed.

In summary, through the static and dynamic load test of the corrugated steel web bridge, the actual working state and dynamic performance of the bridge under the test load are known, which provides the evaluation basis for the normal use of the bridge and basic data for similar projects.

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