Detection and Evaluation of the Bearing Capacity of Railway Steel Plate Girder Bridges

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Abstract: To ensure the safe operation of existing railway bridges, it is necessary to conduct comprehensive inspections of their bearing capacity and actual working conditions on a regular basis. In this paper, taking the 2# steel plate girder bridge on Qinglv Branch Heihe as an example, the appearance inspection, pier and abutment strength test, static load test and dynamic load test were carried out on this steel plate girder bridge, and the content and method of the comprehensive test of the steel plate girder bridge were explained; Based on the test results, the working condition of the bridge was evaluated, hoping to provide reference and reference for other similar bridge type inspection and reinforcement work.

1.Introduction
Bridges are the throat of railway lines and are of great significance to ensure the smoothness and safety of railway transportation. So far, there are more than 200,000 railway bridges in China. With the increase of the service life of the bridge, the speed increase of the line, the increase of the load and other factors, the working condition of the existing railway bridges will be deteriorated, and various diseases will result in a decrease in the carrying capacity. These problems are closely related to structural safety. Therefore, monitoring the carrying capacity of existing bridges and evaluating their service status is an issue that must be paid attention to in line operation [1-4]. This paper takes the 2# steel plate girder bridge on Qinglv Branch Heihe as an example to conduct a comprehensive inspection and assessment of its health status, hoping to provide reference and reference for other similar bridge types.

2.Overview of the bridge
Qinglv Branch Heihe 2# bridge is located at the mileage k191 + 068 of the line. It is a 6-hole 24 m deck steel plate girder bridge. The steel plate girder was mainly built by Shanhaiqian Bridge Factory in 1958. The design grade is medium-22, and the beam height is 1.92 m, and the center distance of the main beam is 2 m, which is a straight bridge.

3.Test scheme

3.1. Purpose
Through the inspection test and evaluation of the Qinglv Branch Heihe 2# bridge, the following inspection objectives were achieved:
(1) Evaluating the overall health status of Heihe 2# bridge;
(2) Appraisal of the bearing capacity of the bridge project;
(3) Providing necessary reference materials for the operation, maintenance and repair of the
3.2 Test content
Bridge testing includes pier and abutment concrete strength testing, comprehensive inspection of bridge appearance, structural static load test and dynamic load test.

3.2.1 Concrete strength testing of piers and abutments
The compressive strength of concrete is greatly affected by the degree of carbonation on the surface of the concrete. In view of the long construction period of the bridge and the greater degree of carbonization, it has an obvious impact on the compressive strength of concrete. Therefore, it is necessary to measure the compressive strength of concrete by springback detection, and find out the compressive strength of concrete of the component to be tested.

3.2.2 Comprehensive inspection of bridge appearance quality
With reference to relevant maintenance regulations [5-6], the overall inspection of the bridge’s appearance quality mainly includes the following. Whether the paint of the bridge steel members is intact, whether there are rust, hard bends, cracks, twists, etc.; bridge abutment concrete surface cracks, crack width and their impact on bearing capacity; whether the bearing position is accurate, whether there are voids and abnormal deformations; bridge deck inspection, road studs and bridge sleeper condition inspection.

3.2.3 Static load test
The static load test is to test the working performance of the bridge superstructure under the design load. The load effect is used to load the vehicle equivalently to make the bridge superstructure respond, that is, the deflection and strain. The measured value is compared with the calculated deflection and strain value of the load to determine the bearing capacity of the bridge superstructure. The testing contents are: the strain of the bearing section; the deflection and strain of the mid-span section.

3.2.4 Dynamic load test
The dynamic load test reflects the dynamic characteristics and dynamic response of the bridge superstructure under the dynamic load. Load the running train to excite the bridge structure and make the bridge superstructure respond to determine the dynamic characteristics and dynamic response of the bridge structure, that is: natural frequency, damping, dynamic strain, impact coefficient, etc., and then compare with the calculated value. The inspection contents are the natural frequency and damping of the beam bridge, the dynamic strain and dynamic deflection of the L/2 mid-span section.

Two DF-4 locomotives were used as the test load. The axle load is shown in Fig. 1. The actual measured train speed adopted the incremental loading method from 10 km/h, 30 km/h, 50 km/h, 60 km/h speed; and the auxiliary test was carried out by the load of passing the train.

3.3 Measuring point layout
The general program of ANSYS structural analysis was used to calculate the internal force and deformation of the current bridge structure under the action of live load, and to determine the section that produces the largest internal force and the section where the largest deformation is located. The
The test bridge was a steel plate girder bridge with 6 holes and 24 meters. The steel plate girder with the first hole was selected as the test object. The finite element model is shown in Fig. 2.

(1) Static load test
The mid-span strain and mid-span bridge deck deflection of the upstream and downstream beams were measured. The layout of each stress measurement point is shown in Fig. 3.

(2) Dynamic load test
The dynamic load test mainly tests the dynamic strain, the dynamic deflection of the mid-span section, and the vibration test of the beam body and part of the pier. Part of the static stress test was selected for dynamic stress. In principle, one test point was selected for each section. The dynamic deflection and vibration measuring points were arranged according to Fig. 4.

4. Test results and analysis

4.1. Strength of pier concrete
The rebound detection of the pier concrete of the bridge was conducted in 10 measuring areas. The compressive strength of the concrete of the bridge pier is 32.5 MPa, which satisfies the requirements of the specification [7].

4.2. Bridge appearance quality
The appearance of the bridge was inspected on the spot, and it was found that the paint on the surface of the steel beams was faded, partially peeled off, and rusted (Fig. 5); the rivets were loose, broken, or missing; the position of the support was accurate, and there was no void or abnormal deformation; The spikes were all corroded, and several spikes were loose and falling off; the bridge ties were severely damaged; the surface of the bridge piers and abutments were cracked densely (Fig. 6), and the concrete at the lower end of the pier was washed off. Therefore, the appearance of the bridge did not satisfy the specification requirements.
4.3 Static load test results

4.3.1 Static stress

The static stress analysis and summary of each measured member are shown in Table 1. According to the measured and calculated values of the static stress of the members, the structural check coefficients of the upper and lower flanges of the upstream and downstream flanges were all less than the standard value 0.85-0.95, indicating that the steel plate beam still has certain safety reserves and its working condition is good.

Table 1. Summary table of measured static stress of rods

| Wheel position | Measuring point location | Number of measuring points | Measured values (MPa) | Calculated value (MPa) | Check coefficients |
|----------------|--------------------------|----------------------------|-----------------------|------------------------|--------------------|
| I 14           | -40.8                    | -63.1                      | 0.65                  |                        |                    |
| I 15           | 19.3                     | 51.4                       | 0.38                  |                        |                    |
| I 12           | -51.7                    | -63.1                      | 0.82                  |                        |                    |
| I 16           | 26.3                     | 51.4                       | 0.51                  |                        |                    |

4.3.2 Mid-span deflection

The measured value of the deflection of the steel plate girder in the middle of the span is shown in Table 2. The vertical deflection-span ratio of the steel plate girder does not exceed 1/1200 as required in the code[8], indicating that the vertical rigidity of the bridge meets the specification requirements.
Table 2. Summary of deflection values in the middle of the span

| Load type               | Measured deflection (mm) | Medium live load deflection (mm) | Deflection-span ratio |
|-------------------------|--------------------------|----------------------------------|-----------------------|
|                         | Upstream | Downstream | Upstream | Downstream |                      |
| Two DF-4 locomotives    | 12.45    | 12.63      | 14.94    | 15.16      | 1/1583               |

4.4. Dynamic load test results
The dynamic load test train adopts DF-4 dual-engines, and the speed of crossing the bridge is from 10 km/h, 30 km/h, 50 km/h, 60 km/h for experimental data collection. Through the peak-peak scanning analysis of the strain-time-history curve and the acceleration-time-history curve recorded by the resistance strain gage and dynamic signal testing and analysis system, the strain, displacement and acceleration amplitude of the bridge structure were obtained; through the amplitude and phase spectrum, power spectrum, and coherence function of each vibration signal analysis, the following test results were obtained.

4.4.1. Dynamic stress
When the test load passes through the bridge, the measured strain and stress values of the beam body mid-span were measured at different speeds. The stress at each measuring point at a speed of 60 km/h is shown in Table 3. The typical dynamic strain time history curve is shown in Fig. 7 and Fig. 8.

Table 3. Summary table of stress at each measuring point at 60 km/h

| Speed (km/h) | Truss number | Measuring point location | Number of measuring points | Measured strain values (με) | Stress values (MPa) |
|--------------|--------------|--------------------------|----------------------------|----------------------------|---------------------|
| 60 Upstream  | 14           | -312.8                   | -65.7                      |                            |                     |
|              | 15           | 282.3                    | 59.3                       |                            |                     |
| 60 Downstream| 12           | -298.0                   | -62.6                      |                            |                     |
|              | 16           | 250.4                    | 52.6                       |                            |                     |
| 60 Upstream  | 14           | -318.0                   | -66.8                      |                            |                     |
|              | 15           | 298.5                    | 62.7                       |                            |                     |
| 60 Downstream| 12           | -307.1                   | -64.5                      |                            |                     |
|              | 16           | 263.3                    | 55.3                       |                            |                     |
4.4.2. Inherent parameters of the bridge

Through the spectral analysis of the pulsation waveform, the natural frequency and damping ratio of the bridge during the pulsation are shown in Table 4. The measured minimum natural frequency of the steel plate girder with a span of 24 meters was 5.81 HZ and greater than 3.54 HZ (The measured transverse natural frequency should not be less than \(45/L^{0.8}\) according to the specification) to meet the specification requirements.

| Analysis results       | Middle of the first hole |
|------------------------|--------------------------|
|                        | Transverse of upstream   | Transverse of downstream | Vertical |
| Natural frequency (Hz) | 5.81                     | 5.83                       | 10.6     |
| Damping ratio          | 5.0%                      | 5.0%                        | 4.9%     |

4.4.3. Acceleration

The measured data of vibration acceleration are shown in Table 5. The maximum measured lateral vibration acceleration of the beam structure was 0.90 m/\(s^2\), which is less than the specification limit of 1.40 m/\(s^2\), indicating that the train has good running comfort and satisfies the specification requirements.

| Test number | Upside 10km/h | Downside 10km/h | Upside 30km/h | Downside 30km/h | Upside 50km/h | Downside 50km/h | Upside 60km/h | Downside 60km/h |
|-------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|
| Upstream    | 0.36          | 0.38            | 0.53          | 0.50            | 0.65          | 0.77            | 0.84          | 0.87            |
| Downstream  | 0.38          | 0.38            | 0.58          | 0.52            | 0.72          | 0.71            | 0.90          | 0.79            |

4.4.4. Amplitude

When the test load passes through the bridge, the measured maximum amplitude value of the upper and lower beam mid-span of the steel plate beam with the first hole was 0.58 mm. Under the locomotive load, in accordance with the regulations in the code [8], the requirements for the safety limit of the transverse amplitude of the bridge span structure for driving were: the plate girder was: \(L/6000 = 4\) mm. The measured maximum amplitude was within the specified range of the specification.
4.4.5. Dynamic deflection
The actual measured deflection waveforms are shown in Fig. 9 and Fig. 10. The measured results show that when the train passes at 60 km/h, the upward and downward deflection-span ratio were 1/1434 and 1/1413, respectively; when the train passes at 50 km/h, the upward and downward deflection-span ratio were 1/1464 and 1/1458, respectively, and all of the vertical deflection span ratios did not exceed the normal value (1/1200) of the vertical deflection-span ratio of the bridge required in the “Inspection Regulations”, and the beam body worked normally.

5. Conclusion
(1) The bridge deck has the problems of failure of some bridge sleepers and over-wide bridge sleeper spacing. The bridge sleepers should be replaced; many bridge deck line spikes warped and the hook bolts are missing, which should be strengthened and replaced in time.

(2) The piers of the bridge have been reinforced with hoop in the past, but the cracks of the reinforced layer are serious. There are many cracks in the pier body, especially at the top of the pier, and the width is also too large. It needs to be sealed and strengthened in time. It is recommended that the cracks of the bridge pier and abutment should be treated with deep-seated grouting, and then the high-strength reinforced concrete should be used to seal the cracks and strengthen the overall structure of the pier and abutment.

(3) Although the bridge span structure can meet the requirements of the specification, the strength reserve is relatively low. To ensure the safety of operation, steel girder reinforcement is recommended, and measures such as vertical longitudinal joint reinforcement, transverse joint reinforcement and steel plate reinforcement can also be adopted.

(4) Bridges, as the throat of transportation, must be inspected regularly and comprehensively, especially the existing old railway bridges with a long service life. Through health status detection, the correct assessment of its safety performance can be obtained to provide a reference basis for maintenance and reinforcement, and ensure operational safety.

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