Mechanical Behavior Analysis of Long-span Steel Truss Arch Bridge Based on Static Load Test

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Abstract: In order to inspect mechanical behavior analysis of long-span steel truss arch bridge, the spatial finite element model was established to analyze the mechanical behavior of the structure under static load and mobile load. Static load test of three span continuous steel truss arch bridge was carried out. The strains, deflection and the tension of the slings were measured. Comparison of testing data with the theoretical values obtained from finite element analysis was carried out. The results showed that the strength and stiffness of the bridge met the design requirements, and the static load test results were basically consistent with the theoretical analysis, which verified the mechanical characteristics of the bridge.

1. Information
The steel truss arch bridge is a kind of traditional bridge structure. It combines the rigid truss arch with the flexible hangers, and forms a strong and soft, complementary effect, has a better architectural landscape. The application of this type of bridge is available in both domestic and overseas combined highway and railway bridges and highway bridges [1][2]. At present, the research on large span steel truss arch bridge is mainly focused on the theoretical analysis and numerical simulation, and few studies on the actual bridge test to verify the mechanical characteristics of the bridge type and evaluate the safety of the structure.

In this paper, the mechanical behavior analysis and safety performance of long span three span continuous steel truss arch bridge were studied, which will provide some reference for the design, construction and maintenance of the similar steel truss arch bridge in the future.

2. Project Overview
This project is three span continuous steel truss arch bridge which the span combination of the bridge is 108m+288m+108m. The main bridge deck width is 43.5m. The main truss was consisted of 2 steel trusses, and the “N” truss with 12m of internode length was used. The sagittal height of the main span arch is 55m, and the vector span ratio is about 1/4.8. The second-degree parabolic lines were used in the axis of the lower chord arch and part of the upper chord arch. Welded box sections were used for upper chord bars, lower chord bars and tie bars of main truss, the cross sections size were 1m×1.3m~1.84m, the inclined bars and the vertical bars of the main truss was consisted of the “H” cross sections. The upper chord of the main truss, the upper and lower chords of the arch ribs, and the diagonal legs of the main truss were provided with diamond shaped couplers, the bars were "I" shaped sections, and the cross section was high 0.52m~0.62m. A cross connection which was triangular truss form was set for every two internodes. The hangers adopt integral extrusion cables, and the standard value of tensile strength of steel strand was 1860MPa. The design load was highway -I level, the pedestrian load was 3.5kN/m².
3. Mechanical behavior analysis

3.1 Finite element model
In this paper, the bridge structure analysis software Midas Civil was used as the platform, considering all kinds of loads during the operation stage of the bridge, building a spatial model as shown in Figure 1.

![Finite Element Model](image)

Figure 1. Finite Element Model

3.2 Analysis of mechanical behavior under the action of moving load
Under the action of moving load (including vehicle load and pedestrian load), the load effect of the main truss member was shown in Figure 2 to Figure 5. The effect of moving load reached 25% of the permanent load. Under the action of moving load, the axial stress of the lower chord bars at the middle position of side span, the one forth-span to the middle chord, and the lower chord bars at the middle fulcrum and the junction between the arch and beam were larger. The maximum deflection of the mid span upper chord bar and tie bar was 50mm and 72mm, reaching 19% and 21% of the permanent load. Compared with the cable stayed bridge and suspension bridge, the steel truss arch bridge has a better vertical stiffness. [3][6]

![Stress Diagrams](image)

Figure 2. The arch stress diagram corresponding to the maximum axial force (unit: kN/m²)

Figure 3. The arch stress diagram corresponding to the minimum axial force (unit: kN.m)

Figure 4. Maximum displacement diagram (unit: mm)

Figure 5. Minimum displacement diagram (unit: mm)

4. Content and method of static load test
In order to fully understand the mechanical behavior of the long-span continuous steel truss arch
bridge under test load, according to the above analysis, 13 kind of loading tests combination of specification were carried out to test the key parts of the bridge. The main loading conditions were as follows: ① Maximum pressure of upper chord bar at middle position of side span, maximum deflection of upper chord bar at middle position of side span, maximum pulling force of lower chord bar at middle position of side span, maximum deflection of lower chord bar at middle position of side span.② Maximum pulling force of top chord bar of the middle fulcrum, maximum pressure of lower chord arch at arch foot, maximum pressure of upper chord bar at one forth-span of main span, maximum deflection of upper chord bar at one forth-span of main span, maximum deflection of tie bar at one forth-span of main span.③ Maximum pressure of upper chord bar at middle position of main span, maximum deflection of upper chord bar at middle position of main span, maximum pulling force of tie bar at middle position of main span, maximum deflection of tie bar at middle position of main span.

Static load test carried out as equivalent loading by 18 trucks with about 370kN, the static load test efficiency coefficient \( \eta_q \) was used to control the size and location of the test load, the value is generally in 0.95~1.05. \[ \text{(1)} \]

\[
\eta_q = \frac{S_s}{S(1 + \mu)}
\]

Where: \( \eta_q \) was the static load test efficiency coefficient. \( S_s \) was the maximum computational effect of internal force, stress or displacement of the loading control section corresponding to a loading test item, under the action of static test load. \( S \) was the calculated value of the most adverse effect of the internal loading, stress or displacement of the same loading control section produced by the calculation load. \( \mu \) was impact coefficient used by specification.

The test section of this static load test was shown in Figure 6. Section 1-1: maximum pressure of upper chord bar at middle position of side span, test strain and deflection. Section 2-2: maximum pressure of lower chord bar at middle position of side span, test strain and deflection. Section 3-3: maximum pulling force of upper chord bar at the middle fulcrum, test strain. Section 4-4: maximum pressure of lower chord arch at arch foot, test strain. Section 5-5: maximum pressure of upper chord bar at one forth-span of main span, test strain and deflection. Section 6-6: maximum deflection of tie bar at one forth-span of main span, test strain and deflection. Section 7-7: Maximum pressure of upper chord bar at middle position of main span, test strain and deflection. Section 8-8: Maximum pressure of tie bar at middle position of main span, test strain and deflection. Section 9-9: Cable force test of hanger E11a and E11b.

\[ \text{Figure 6. Schematic diagram of test section (unit: mm)} \]

5. Main test results and analysis

5.1 Measuring points’ strains of arch and tie bars
Measuring points’ strain of arch and tie bars were shown in Table 1. The tensile strain in the table was positive. The strain values were the maximum in the loading condition. The strains’ check coefficients were in 0.76~0.98, all less than 1.0. It was shown that the main control section strain can meet the normal requirements when the test load was close to the design load effect. The relative residual strains at each test point were between 0~7.1%, all less than 20%, it was shown that the upper
structure of the main bridge had better resilience when approaching the test load of the design load effect.

Table 1 Strains of main measuring point

| Section | Measured value (με) | Theoretical value (με) | Check coefficient ξ | Residual value (με) |
|---------|---------------------|------------------------|---------------------|---------------------|
| 1-1     | -116                | -140                   | 0.83                | 0                   |
| 2-2     | 47                  | 57                     | 0.83                | 2                   |
| 3-3     | 91                  | 95                     | 0.96                | 7                   |
| 4-4     | -72                 | -92                    | 0.78                | -1                  |
| 5-5     | -99                 | -120                   | 0.83                | -5                  |
| 6-6     | -105                | -107                   | 0.98                | -6                  |
| 7-7     | 39                  | 51                     | 0.76                | 0                   |

5.2 Measuring points' deflections of arch and tie bars

Measuring points' deflections of arch and tie bars were shown in Table 2, deflection was downward positive. The deflections' check coefficients were in 0.45~0.79, all less than 1.0. It was shown that the stiffness of the upper structure of the main bridge can meet the normal requirements when the test load was close to the design load effect. The relative residual deflections at each test point were between 0~8.8%, all less than 20%, it was shown that the upper structure of the main bridge has better resilience when approaching the test load of the design load effect.

Table 2 Deflection of main measuring point

| Section | Measured value (mm) | Theoretical value (mm) | Check coefficient ξ | Residual value (mm) |
|---------|---------------------|------------------------|---------------------|---------------------|
| 1-1     | 19.8                | 24.99                  | 0.79                | 1.9                 |
| 2-2     | 12                  | 26.58                  | 0.45                | 0                   |
| 5-5     | 26.3                | 52.93                  | 0.5                 | 0                   |
| 6-6     | 34.5                | 63.92                  | 0.54                | 0                   |
| 7-7     | 37.1                | 49.97                  | 0.74                | 1.3                 |
| 8-8     | 55.4                | 71.82                  | 0.77                | 0.4                 |

5.3 Internal force increment tests of hangers

Measured values, theoretical values and calibration coefficients of hanger E11a and E11b under test load were shown in Table 3.

Table 3 Internal force increment of hangers

| Hanger number | Measured value (kN) | Theoretical value (kN) | Check coefficient ξ |
|---------------|---------------------|------------------------|---------------------|
| E11a          | 299                 | 321                    | 0.93                |
| E11b          | 299                 | 321                    | 0.93                |

As shown in table 3, the checking coefficients of tension increment of hanger E11a and E11b were all 0.93, which satisfied the requirement that the calibration coefficient is not greater than 1.

To sum up, under the static load, the actual mechanical state of the bridge was basically consistent with the theoretical calculation. Under the test load near the design load, the measured strains and deflections were less than the theoretical values, and the calibration coefficients were less than the specification requirements. After unloading, the strains and deflections had a good return to zero indicated that the stiffness and strength of the structure met the design requirements and the structure was in elastic stress state. When calculating the measured internal force of hangers, accurate results can be obtained by measuring the natural frequency and combining with finite element simulation.
6. Conclusions

1) The mechanical characteristics of the bridge were verified by the static load test. Under the equivalent static load, the strain and deflection of the key positions of the steel truss arch bridge were in agreement with the theoretical analysis.

2) Under the test load close to the design load effect, the check coefficients of the stress and strain of upper chord bar at the middle fulcrum and the middle span of the main span were 0.96 and 0.98 respectively, indicating that the safety reserve was small, and should be paid attention to during the design and construction of the same type bridge and operation stage.

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