Analysis of Static Load Test of a Masonry Arch Bridge

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Abstract. In order to know whether the carrying capacity of the masonry arch bridge built in the 1980s on the shipping channel entering and coming out of the factory of a cement company can meet the current requirements of Level II Load of highway, through the equivalent load distribution of the test vehicle according to the current design specifications, this paper conducted the load test, evaluated the bearing capacity of the in-service stone arch bridge, and made theoretical analysis combined with Midas Civil. The results showed that under the most unfavorable load conditions the measured strain and deflection of the test sections were less than the calculated values, the bridge was in the elastic stage under the design load; the structural strength and stiffness of the bridge had a certain degree of prosperity, and under the in the current conditions of Level II load of highway, the bridge structure was in a safe state.

Keywords: Masonry Arch Bridge, Static Load Test, stress, deflection

1. Introduction

Load test is the main technical method to detect the bearing capacity of in-service bridges. It is one of the most effective and direct means by which we can know the performance parameters of a bridge, analyze its actual working state and evaluate its operation status. [9]

The engineering background of this paper is an in-service stone arch bridge on a Class-3 Highway in Yunnan Province (see Figure 1). First, the overall appearance of the bridge was examined, and the service conditions of the bridge in recent years were investigated. And then, theoretical analysis was made on the bridge with Midas Civil bridge structural analysis software. On this basis, the experimental scheme was developed. With HY-65B3000B Digital Static Strain Sensor, RS-QL06E Bridge and Structural Stress Detection System and dynaflect, the static load test was conducted on the masonry arch bridge to evaluate whether the bridge met the current requirements of Level II load of highway.

2. Overview of the project
The bridge is located on the shipping channel entering and coming out of the factory of a cement company. It was built and opened to traffic in the 1980s. Because the bridge was completed too early and design data was missing, this paper first made the overall routine inspection on the bridge, measured a series of dimension data and did the strength test to establish the calculation model.

The structure of the bridge is a deck type masonry arch bridge; the span of the main arch is 30m, the span of the web arch is 6m; the width of deck: net 6.4+2×0.3=7m; there are two two-way lanes; the thickness of the arch ring of the main arch is 84cm; the thickness of the arch ring of the web arch is 42cm; and the arch ring is 7m wide.

The main arch ring, bridge deck, web arch and piers are all made of stones. The strength grade was determined in the laboratory with the core drilling and sampling method. The specimen size is 75×75×75mm, the determined intensity is 46.2Mpa, and the softening coefficient is 1.79. The bridge deck pavement and guardrail were renovated from the original stones to concrete. The strength grade is unknown (the data is not found or verified). The strength grade of this part has little effect on the overall calculation of the bridge, so the drilling core and sampling test was not done for it.

| Material code | Unit type                  | Material type            | Young's modulus (MPa) | Gravity density (kN/m³) | Coefficient of linear expansion 1/℃ |
|---------------|----------------------------|--------------------------|-----------------------|-------------------------|------------------------------------|
| 1             | Bridge pier, main beam, main tower | Concrete 50              | 3.45E+04              | 26                      | 1.00E-05                           |
| 2             | Stay Cables                | High strength steel wire | 1.95E+05              | 78.5                    | 1.20E-05                           |
| 3             | Prestressed steel wire     | High strength steel wire | 1.95E+05              | 78.5                    | 1.20E-05                           |

### 3. Scheme of the static load test

According to the principle of internal force equivalence required by the load test, in the design of the loading scheme, this paper tried its best to make the internal forces of the test sections equal or similar under the load of the test vehicle and Level II load of highway.

#### 3.1 Test conditions

Combined the theoretical calculation, 5 working conditions of the stone arch bridge in the worst stress state were selected for the static load test, including Working Condition 1-maximum vault of the main arch and full load for positive bending moment; Working Condition 2-maximum vault of the main arch and unbalanced load for positive bending moment; Working Condition 3-maximum positive bending moment of L/4 cross section of the main arch; Working Condition 4-maximum positive bending moment on the vault of No. 2 Web Arch; and Working Condition 5-maximum axial force at the arch foot. The schematic diagram of loading under different conditions is shown in Figure 2.

![Figure 2](image-url)
According to the actual situation of the operation of the bridge, a 350kN (weight of the vehicle + weight of load) three axle vehicle was used for the test. Its wheelbase and axle load are as shown in Figure 3. According to requirements of Test Procedures of Load of Highway Bridges, $\eta$, the test load efficiency coefficient of test section, shall be at least 0.80. Combined with the previous calculation, it is determined that the static load test needs a total of two vehicles, whose model, wheelbase and axle load are shown in Table 2.

| Car                  | Wheelbase /m | Axle load /kN | Total /kN |
|----------------------|--------------|---------------|-----------|
| 1〜2                  | 3.6          | 1.4           | 60        |
| 2〜3                  | 3.5          | 1.4           | 46        |
| 1                     | 3.6          | 1.4           | 56        |
| 2                     | 3.5          | 1.4           | 46        |
| 3                     | 3.6          | 1.4           | 56        |
| 4                     | 3.5          | 1.4           | 46        |
| 5                     | 3.6          | 1.4           | 56        |

Figure 3 Loading car models

3.2 Test cross section

There are four stress test sections, including arch foot section (Section I - I), L/4 cross section (Section II-II), midspan cross section (Section III-III) and web arch vault section (IV- IV). The locations of the test sections are shown in Figure 4. Five measuring points for each section are as shown in Figure 5. Due to the restriction of site conditions, it was difficult for the cantilever end of the bridge inspection vehicle to enter the web arch section. The bridge deck was not flat and working conditions of the bridge inspection vehicle were not good, so only 1 strain gauge was installed. The strain test was conducted with HY-65B3000B Digital Static Strain Sensor and the static strain testing system.

Figure 4 Stress test section

Figure 5 Deflection test section

3.3 Deflection test section

There are five deflection control sections, including mid-span cross section (Section III-III), L/4 cross section (Section II- II section), arch foot section (IV - IV), web arch vault section (Section I - I).
and Section V-V) of the arch bridge, whose positions are shown in Figure 5. The deflection points were arranged on the bridge deck. Three measuring points on the same test section are shown in Figure 3. The deflection under various working conditions was tested with a high-precision level gauge. The deformation of the mid-span section of the main arch was tested with a deflection tester.

![Deformation measuring point layout/cm](image1)

![Calculation model](image2)

4. Theoretical calculation

In the theoretical analysis of the static load test, Midas Civil, bridge structure analysis software, was used for calculation. The part filled between the web arches and the web arch and the main arch was converted into the unit load by hand and added to each arch ring unit for simulation. Main calculation:

1) The efficiency coefficient of load (test internal force/design internal force) shall range from 0.8 to 1.05 [10];
2) The stress and deformation of each test cross section under the test load.

The calculation results of the efficiency coefficient of this test are shown in Table 3. The effect of the impact coefficient has been included in the calculation. The efficiency coefficients of all measuring points meet the requirements of the relevant codes and range from 0.8 to 1.05.

| Position | Efficiency Coefficient of Condition 1 | Efficiency Coefficient of Condition 2 | Efficiency Coefficient | Efficiency Coefficient | Efficiency Coefficient | Efficiency Coefficient |
|----------|---------------------------------------|---------------------------------------|------------------------|------------------------|------------------------|------------------------|
| 3-1      | 0.97                                  | 0.99                                  | 0.99                   | 1.01                   | 1.01                   | 0.91                   |
| 3-2      | 0.93                                  | 0.98                                  | 1.02                   | 1.02                   | 1.02                   | 0.89                   |
| 3-3      | 0.91                                  | 1.02                                  | 1.00                   | 0.99                   | 1.3                    | 0.89                   |
| 3-4      | 0.93                                  | 0.99                                  | 1.01                   | 1.02                   | 1.02                   | 0.89                   |
| 3-5      | 0.98                                  | 1.01                                  | 0.98                   | 1.03                   | 1.03                   | 0.91                   |

5. Test results

The comparison between measured values and theoretical calculation values of L/4 and L/2 section of the main arch and vault section and arch foot section of the web arch is shown in Figure 9. The measured values of all measured points are smaller than the calculated values. 30% of the measuring points have residual deformation, and the relative residual deformation is 12%-18%. There is no new crack in the test process. The calibration coefficient of deformation ranges from 0.51 to 0.67.
The measured value of strain at the lower edge of each test section was multiplied by the elastic modulus of stone material to calculate the measured value of stress, which was compared with the theoretical value, and the calibration coefficient was calculated (see Table 4). In the table, the measuring points with data interference which cannot be collected with instrument in each section have been eliminated. The calibration coefficient is 0.48-0.55, and the relative residual strain of the stress measurement points is 2%-12%, which are less than the limit value of 20% in the specification.

| working Condition | Measuring point number | Calculated value | Measured value | Calibration coefficient |
|-------------------|------------------------|------------------|----------------|-------------------------|
| No.1              | 3-1                    | 1.35             | 0.72           | 0.53                    |
|                   | 3-2                    | 1.38             | 0.66           | 0.48                    |
|                   | 3-3                    | 1.53             | 0.80           | 0.52                    |
|                   | 3-5                    | 1.35             | 0.72           | 0.53                    |
|                   | 3-1                    | -0.85            | -0.42          | 0.49                    |
|                   | 3-2                    | -0.63            | -0.33          | 0.52                    |
| No.2              | 3-3                    | 1.55             | 0.79           | 0.51                    |
|                   | 3-4                    | 1.61             | 0.84           | 0.52                    |
|                   | 3-5                    | 1.55             | 0.74           | 0.48                    |
|                   | 4-1                    | 1.53             | 0.75           | 0.49                    |
| No.3              | 4-2                    | 1.68             | 0.80           | 0.48                    |
|                   | 4-3                    | 1.78             | 0.98           | 0.55                    |
| Mo.4              | 2-1                    | 1.72             | 0.91           | 0.53                    |
|                   | 1-3                    | 2.25             | 1.10           | 0.49                    |
| No.5              | 1-4                    | 2.32             | 1.21           | 0.52                    |
|                   | 1-5                    | 2.35             | 1.20           | 0.51                    |

6. Conclusion
According to the current design specifications and current requirements of Level II load of highway, the equivalent load distribution was made. The test results of stress and deformation of each section under the test conditions show that:

1) In the loading process, the stone arch bridge was in the elastic working stage, and there was no new crack. After the unloading of the vehicle, the load on the sections returned to zero normally,
which proved that the bridge was in a safe state under the test load conditions, and the strength of the main load-bearing components met the requirements of the current design specifications.

2) The measured values and calibration coefficients of stress and displacement of sections of the bridge are in the safety range specified by the specifications, indicating the overall working performance of the masonry arch bridge is good.

3) The masonry arch bridge was opened to traffic a long time ago. The component materials have different degrees of weathering. The surface layer of cement mortar of each component has different degrees of falling, which affects the safety performance of the structure to a certain extent. The bridge shall be inspected and maintained regularly. The static test results show that the bridge is in a safe state under the test load (including unbalanced loading), but the calibration coefficient is small. In the future operation, a single truck shall run at low speed on the bridge.

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