Evaluation of bearing capacity of reinforced stone arch bridge based on static load test

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Abstract. In order to evaluate the stress and working performance of a reinforced stone arch bridge, the load test of the bridge is carried out. Static load test is to test the stress and displacement of each section of the main arch ring under the action of partial load and medium load. The results show that under the action of various loads, the check coefficients of deflection and strain of this bridge do not exceed the specification limit of 1.0 of masonry arch bridge, the actual working performance of the structure is good, the maximum value of relative residual strain and relative residual deformation are 11.11% and 8.21% respectively, and they do not exceed the standard allowable value of 20%, and the whole bridge is in the elastic deformation stage. The test results show that the reinforcement method of thickening the main arch ring has good application value, can effectively improve the service level of the old bridge and prolong the safety service life, and has obvious social and economic benefits.

1. Introduction

Arch is a kind of structure bearing type with long history and wide application. Under vertical load [1], the arch is mainly under axial compression, which can make full use of masonry materials with good compressive properties to construct arch Bridges. In mountainous areas rich in stone materials, stone arch Bridges are usually preferred in order to meet local traffic needs and consider local materials, low cost and other factors, especially suitable for crossing gullies or streams.

Due to the limited span, the construction means of small and medium-sized stone arch Bridges are relatively single, that is, the masonry method [2-3] is adopted, with the arch frame or arch tire as the support, the natural stone (stone, block or stone) is gradually formed as the bearing structure according to the grouting or dry laying process. Restricted by the technical and economic conditions at that time, the load standard of such local Bridges is low, professional design is lacking, construction quality is not easy to be controlled [4], and there is a lack of maintenance during operation. As a result, structural diseases appear constantly with the increase of bridge age and the change of service conditions. A large number of investigations on stone arch Bridges show that the masonry quality of small and medium-sized span stone arch Bridges has great variability.

Growing along with the economic development of traffic, local service performance of highway Bridges is generally faced with higher requirements [5]. Therefore, the bearing capacity of a large number of stone arch Bridges in service can be evaluated through testing after reinforcement and maintenance, which can improve the service level of old Bridges and extend their safe service life, and
has obvious economic and social benefits. Based on the results of dynamic load test, this paper analyzes the load-bearing capacity of the reinforced stone arch Bridges.

2. Project summary

The bridge is located at K73+105 of a national highway. The original bridge was completed and opened to traffic in 1993. Due to the construction of road reconstruction and expansion project in this section, the bridge was reinforced with loads. Before reinforcement, the net span of the bridge is 50.00m, and the thickness of the main arch ring is 1.0m. After reinforcement of the main arch ring with C40 concrete, the net span of the bridge is 49.52m, the net vector height is 8.03m, the net vector span is 1/6.17, the width of the main arch ring is 8.5m, and the thickness is 1.3m. The cross section size of the main arch wall is 8.5×3.0m, and the cross section size of the upper arch hole is 8.5×1.0m. The original design load of the bridge is car-20, trailer -100, and the load level of the strengthened bridge is highway -I.

Midas Civil bridge finite element analysis software was used for the calculation tool, and beam element simulation was used for the main arch ring. By applying static load to the model, strain and displacement values of each measured point in each test section of the structure were obtained, and then compared with the measured values after the real bridge was loaded to evaluate the bearing capacity of the bridge.

3. Bridge beam static load test

3.1. Principle of static load test

Static load test is mainly used to test the strain, displacement, residual strain and residual deformation of each control section measuring point of the upper main structure of the bridge [6], and comprehensively evaluate the performance of the main structure of the bridge. According to the calculation and analysis, it is determined that the static load test of the bridge needs 4*480kN double axle heavy cars, which are loaded at the most unfavorable position of the influence line of internal force on the control section of the main structure, so that the efficiency coefficient of the test load is between 0.85 and 1.05. Figure 1 shows axle weight and wheelbase when the test vehicle is fully loaded.

Strain test: strain gauge is decorated in the corresponding test section at the bottom of the main arch ring and its resistance to 120Ω, sensitivity coefficient is 2.08, the distance of 10cm, use DH3819 wireless static strain test and analysis system to collect data.

Deflection test: a hook is set at the bottom of the main arch ring of each control section and a wire is suspended on the hook. A weight hammer is suspended at the bottom of the wire. A dial indicator is set under the weight hammer.

![Figure 1. Test vehicle](image)

3.2. Test section and measuring point arrangement

In order to reflect the bearing capacity of the bridge comprehensively, the main arch span of the bridge is taken as the test span. The test sections are 3, namely the 0# arch foot section JM1, The quarter span section JM2, and the half span section JM3. The specific layout is shown in Figure 3. The strain measuring points of JM1, JM2 and JM3 sections are arranged under the main arch ring. Five
measuring points are arranged at the bottom of the arch ring for each section, and a total of 15 strain measuring points are arranged. The deflection measuring points were arranged on JM2 and JM3 sections. Two measuring points were arranged horizontally for each section, and a total of four measuring points were arranged. The arrangement of strain and deflection measuring points is shown in Figure 2.

3.3. Test conditions and load arrangement

The static load test of the bridge beam determines the test condition according to the most unfavorable force principle of the bridge structure. The structure is calculated to be 480kN loaded at the most unfavorable position in the longitudinal direction of the bridge, and the transverse direction is divided into partial load and medium load. The test content is deflection and strain of the control section under the action of test load. The load test process is shown in Table 1.

![Figure 2. Test section layout (unit: cm)](image)

| Load condition | The control section | Spacing         | Loading way | The test content |
|----------------|---------------------|-----------------|-------------|-----------------|
| Condition 1    | JM1                 | Maximum negative moment | Partial load | Strain          |
|                | JM1                 |                 | Middle load |                 |
| Condition 2    | JM2                 | Maximum positive moment | Partial load | Deflection and strain |
|                | JM2                 |                 | Middle load |                 |
| Condition 3    | JM3                 | Maximum positive moment | Partial load | Deflection and strain |
|                | JM3                 |                 | Middle load |                 |

3.4. Static load test efficiency

In order to meet the requirements of load effect, the number and axle weight of test vehicles are selected according to the principle of control internal force equivalent, which makes the quiet load efficiency \( \eta_q \) between 0.85 and 1.05. The loaded vehicles are weighed before the test. The load efficiency is calculated according to Equation (1) [6]:

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

where

- \( S_s \) -- the maximum calculated effect value of internal force or displacement in the loading control section corresponding to a loading test item under static load test load;
- \( S \) -- The calculation value of the most adverse effect of internal force or displacement in the control section under the same load generated by the control load;
- \( \mu \) -- Value of impact coefficient as per specification.
In the test load analysis, the 2-lane load was considered, and the impact coefficient was considered in the design load, but the lateral reduction was not considered. The $\eta_q$ of the static load efficiency is between 0.85 and 1.05 by adjusting the loading position, loading tonnage, etc. See Table 2 for the value of the bridge's static load efficiency.

| Condition  | $M_s$ (kN.m) | $M_t$ (kN.m) | $\eta_q$ |
|------------|--------------|--------------|----------|
| Condition1 | -2267.3      | -2478.3      | 0.91     |
| Condition2 | 1150.7       | 1202.8       | 0.96     |
| Condition3 | 2287.0       | 2372.3       | 0.96     |

4. Analysis of test results

4.1. Analysis of strain test results

Under the action of various working conditions, the measured strain value $S_e$, calculated value $S_s$, residual value $S_p$ and relative residual value $S_p$ of test section 1~3 are shown in Figure 3~ Figure 5.

![Figure 3. Strain values at working conditions 1](image)

![Figure 4. Strain values at working conditions 2](image)
It can be seen from the above figure that under the test load of working conditions 1~3, the range of strain check coefficient of each measuring point is less than 1.0, and the variation along the transverse direction is not big. The static load test results show that the strength of the superstructure of the bridge meets the design load (level-I highway) and the specification requirements, and the lateral stiffness is also large.

4.2. Analysis of deflection test results

Under various working conditions, the measured deflection value $f_e$, theoretical value $f_s$, residual value $f_P$ and relative residual deformation value $f_P'$ of the measuring point of 1#~4# point are presented in Table 3.

| Condition | Loading way | Point |  $f_e$/mm |  $f_P$/mm |  $f_s$/mm | $\eta(f_e/f_s)$ | $f_P'$  |
|-----------|-------------|-------|-----------|-----------|-----------|----------------|--------|
| Condition 2 | Partial load | 1# | 1.23 | 0.11 | 3.45 | 8.21 | 0.36 |
|            | 2# | 1.04 | 0.09 | 3.45 | 7.96 | 0.30 |
|            | The average | 1.14 | / | 3.45 | / | 0.33 |
|            | 1# | 1.11 | 0.07 | 3.45 | 5.93 | 0.32 |
|            | Middle load | 2# | 1.17 | 0.01 | 3.45 | 0.85 | 0.34 |
|            | The average | 1.14 | / | 3.45 | / | 0.33 |
|            | 3# | 2.67 | 0.13 | 5.03 | 4.64 | 0.53 |
|            | Partial load | 4# | 2.34 | 0.12 | 5.03 | 4.88 | 0.47 |
|            | The average | 2.51 | / | 5.03 | / | 0.50 |
| Condition 3 | Partial load | 3# | 2.49 | 0.15 | 5.03 | 5.68 | 0.50 |
|            | Middle load | 4# | 2.56 | 0.11 | 5.03 | 4.12 | 0.51 |
|            | The average | 2.53 | / | 5.03 | / | 0.50 |

As can be seen from the above table, the measured relative residual deformation at each deflection measurement point is less than the limit value (20%) specified in literature [6], the check coefficient of deflection at each measurement point is less than 1, the measured deflection is far less than the specification requirement (L/600), and no horizontal displacement occurs at the arch foot under the test load of each working condition. The static load test results show that the stiffness of the bridge superstructure meets the design load (highway -I class) and the specification requirements.
5. Conclusion of static load test

1) Under the action of the equivalent static load with the load efficiency not less than 0.85, the relative residual of each deflection and strain measuring point is less than 20%, indicating that the structure is under an elastic state of stress;

2) The deflection and strain check coefficients of the measuring point are all less than 1; There is no horizontal displacement at the foot of the arch under various test loads;

3) To sum up, the strength and stiffness of the superstructure of the bridge meet the design load (class I-highway) and specification requirements;

4) The reinforcement method of thickening the main arch ring has good application value, can effectively improve the service level of the old bridge and extend the safety service life, and has obvious social and economic benefits.

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