Research on Construction Control of Vertical Rotation of Concrete-filled Steel Tubular Basket Arch Bridge

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Abstract. This paper focuses on the theme of bridge construction control, using the finite element analysis and calculation program as the platform, taking a concrete-filled steel tube concrete basket arch bridge as the research object, combining the theoretical foundation of the concrete filled steel tube basket arch bridge, and using finite element software to simulate the rotating structure in three dimensions. Simulation, analysis of the force status and longitudinal and lateral changes of the rotating structure at various angles and when closing, and the structural stability analysis of the rotating process. The most unfavorable stress conditions and the most vulnerable to instability conditions are determined. And through simulation, the accuracy of the line shape of the steel pipe arch rib in the vertical rotation process, the accuracy of the arch axis detection and the accuracy of the elevation detection are estimated.

1. Introduction

With the vigorous development of the national economy, the scale of various construction projects has been expanding day by day. The expansion of the project scale and the complexity of the structural system have brought about the complexity and safety of the construction process. Concrete-filled steel tube has the advantages of good compressive performance, high bearing capacity, and convenient construction. The application of concrete-filled steel tube to arch bridges solves the two major problems of material self-weight and construction difficulties that restrict the development of arch bridges to large spans [1]. Compared with the rapid development of concrete-filled steel tube arch bridges in engineering applications, as a bridge type that uses new materials, the theoretical research of concrete-filled steel tube arch bridges is still immature and complete. At present, no specific design and construction of concrete-filled steel tube arch bridges has been issued at home and abroad. Procedures and specifications [2, 3].

At the same time, with the increasing application of concrete-filled steel tube arch bridges in China, its spans continue to increase, its scale is increasing, and the bridge types are becoming more and more diverse and rich in individuality, coupled with the geological conditions of each bridge. It is very different from the surrounding environment, prompting the construction methods and construction technology of concrete-filled steel tube arch bridges to continuously introduce new ones [4]. As a result, almost every concrete-filled steel tube arch bridge has innovations and specialties in the
construction process, and it is greatly affected by the site climate conditions and hydrogeological conditions. It is especially necessary to analyze the construction process.

2. Relying on engineering
A certain bridge (Figure 1) is at an angle of 110º to the direction of the line, and an angle of 70º to the direction of water flow. The main bridge adopts a 40+200+40m half-supported basket-carrying arch bridge structure with a bridge deck width of 51.6 meters. The main arch ribs are steel pipe arches, and steel beams are used between the main span arches. The road grade of this bridge is expressway; the design speed is 100km/h; the design load is highway-level I load. The main arch structure mainly consists of arch ribs, lateral connections, columns, beams, longitudinal beams, suspenders, tie rods, bridge deck systems, and arch base foundations.

![Figure 1. Overall view of the bridge.](image)

After careful study and discussion by experts, the vertical lifting scheme is adopted. This plan disconnects the main arch rib from the middle of the span (but avoids the middle cross brace), reserves a 0.3m closed section, and installs four lifting towers in the middle of the first cross brace and the first cross brace of the arch rib. The arch rib is assembled horizontally on the projection line of its vertical position (including the corresponding transverse bracing), and the arch rib that has completed the low-position horizontal assembly is pulled into position by the continuous tension jack installed on the lifting tower, and the two After the side arch ribs are vertically turned into position, the closed section is installed by a crawler crane to complete the arch rib assembly construction. Due to the low-position assembly, the welding efficiency can be improved, and the arch rib assembly and adjustment are more convenient, and the high-altitude operation is reduced [5].

3. Simulation analysis

3.1. Simulation of Concrete Filled Steel Tubular Arch Ribs
In the analysis of the construction stage of the concrete-filled steel tube arch bridge, the section of the arch rib is simulated by Midas’ joint section of the construction stage. The stiffness of the combined section during the construction phase is the stiffness of the combined section [6, 7]. When Midas conducts the stress analysis of the steel-concrete composite structure (SRC), it is assumed that the steel and concrete are tightly connected, and the Equivalent Sectional Properties are used for calculation and analysis, similar to the converted section method. When calculating the equivalent conversion section characteristic value, the elastic coefficient of steel (Es) and the elastic coefficient (Ec) of concrete are calculated using the steel-shaped concrete standard (SSRC79 (Structural Stability Research Council, 1979, USA)). According to Eurocode4 specification, Ec is reduced by 20%.
3.2. Calculation model and optimization analysis

Using bridge space limited software MIDAS Civil2010 modeling analysis, the model has a total of 831 nodes and 2203 elements. The horizontal struts and diagonal struts of the support adopt truss elements, and the main pipe adopts beam elements. The cross brace and diagonal brace of the cross beam between the brackets adopt truss elements, and the upper and lower chords adopt beam elements. The upper and lower chords and web members of the arch ribs are all beam elements, and the slabs are plate elements. The upper and lower chords of the transverse connection beam between the two arch ribs adopt beam elements, the web members adopt truss elements, and the stay cables adopt rod elements.

According to the plan provided by the construction unit, the stress, displacement and instability of the lifting tower during the construction process will be reviewed and checked, and the optimal plan will be proposed.

3.2.1. Calculation model 1: No beams are added between the two towers, and no cable force is added to the back cables.

A. No crossbeams and no cable force displacement between the two towers

![Figure 2](image)

**Figure 2.** No crossbeams and no cable force displacement between the two towers.

Figure 2 shows that the maximum displacement of the tower top in the longitudinal direction of the bridge is about 12.9cm, and the maximum displacement in the transverse direction of the bridge is about 11.5cm.

B. No cross beams and no back-stayed cables between the two towers

![Figure 3](image)

**Figure 3.** The stress of beam element with no beam and back cable between the two towers.

It can be seen from Figure 3 that there are both tensile stress and compressive stress at the bottom of the tower foot. The maximum compressive stress is 202MPa, the maximum tensile stress is 98.6MPa, the force is unbalanced, and the maximum compressive stress is close to its compressive strength. Insufficient safety reserves [8].

C. Instability mode without beams and back cables between the two towers
Figure 4. Instability mode without beams and back cables between the two towers.

From the above figures, it can be seen that under the calculation model without beams and back cables between the two towers, the tower top displacement and tower foot stress are both large, the critical load instability coefficient is 1.17, and the safety reserve is insufficient.

3.2.2. Calculation model two: add beams between the double towers, back-stay cable force, and lateral stabilizer cable force. The calculation shows that under the calculation model of adding beams, back-stay cables and lateral stabilizing cables between the double towers, the tower top displacement and tower foot stress are much smaller than those without beams between the double towers. After the cable force is applied, the stress at the foot of the tower is all compressive stress, the stress is relatively balanced, the critical load instability coefficient is 21.04, and the structural safety reserve is relatively high.

3.2.3. Model optimization. Through comparison and analysis, a rotating model with beams added between the two towers, back-stay cables, and lateral stabilizing cables is adopted [9].

In order to simulate the overall vertical rotation construction process of the main arch rib, the initial state model of the main arch rib lifting is established, and the state model of the main arch rib is raised to 3°, 6°, 9°, 12°, 15°, 18°, 21°, and the main arch rib is raised to Collapse the position state model.

4. Simulation Calculation of Longitudinal Change of Main Arch Rib in the Process of Vertical Rotation

Figure 5 shows the corresponding displacement, beam element stress, and instability mode graphics of the arch rib lifting initial state (before turning):

Figure 5. Displacement diagram before turning.

From Figure 5, it is known that the maximum displacement of the tower top along the longitudinal direction of the bridge is about 0.6cm, and the maximum displacement along the bridge's transverse direction is about 0.2mm.
Figure 6. Vertical displacement of the front end of the front arch rib of the swivel.

From Figure 6, the maximum vertical displacement of the front end of the arch rib is about 23.4cm.

Figure 7. Stress diagram of front beam element of swivel.

Take the enlarged view of the tower foot stress as shown below:

Figure 8. Stress diagram of the left tower foot before turning.
Figure 9. Stress diagram of the right tower foot before turning.

Figure 10. Stress diagram of arch foot before turning.

Figure 11. The modal diagram of instability before turning.

Figure 12. The modal diagram of instability before turning.
The critical load instability coefficient is 21.04.

In the same way, calculate other states, and the conclusion is as follows:

According to Midas calculation results, during the lifting process, when the main arch rib is lifted to $6^\circ$, the top of the tower has a displacement of 9.8 cm in the longitudinal direction and 0.25 mm in the transverse direction. The displacement is the largest, which is the most unfavorable state of force. Attention should be paid to strengthen control when lifting. The load instability coefficient before the swivel is the smallest, which is 21.04, which means that the initial state of the arch rib before the swivel is the most vulnerable to instability state.

Table 1. Main arch rib lifting process.

| Promotion status | Displacement of the tower top along the longitudinal bridge direction (cm) | Displacement of the top of the tower along the transverse bridge (mm) | Critical load instability coefficient |
|------------------|-------------------------------------------------------------------------|---------------------------------------------------------------------|-------------------------------------|
| $0^\circ$        | 0.6                                                                     | 0.2                                                                 | 21.04                               |
| $3^\circ$        | 9.8                                                                     | 0.2                                                                 | 23.4                                |
| $6^\circ$        | 9.8                                                                     | 0.25                                                                | 23.6                                |
| $12^\circ$       | 9.5                                                                     | 0.3                                                                 | 24.4                                |
| $18^\circ$       | 7.9                                                                     | 0.2                                                                 | 26.1                                |
| $21^\circ$       | 6.3                                                                     | 0.3                                                                 | 27.1                                |
| In place         | 2.5                                                                     | 0.3                                                                 | 27                                  |

Based on the above calculation, during the lifting process of the main arch rib, a certain height difference between the east and west side arches can appear, which will not have much impact on the arch rib lifting process and the final closing. However, as the lifting degree of the arch rib increases, the requirements for the height difference are getting higher and higher. When reaching the closed position, the maximum height difference between the east and west side arch ribs cannot exceed 50.2025 mm, that is, it cannot exceed 5 cm.

In summary, during the lifting process of the main arch rib, there may be a certain height difference between the east and west arches. However, the average height difference cannot exceed 114.27 mm, and the maximum height difference cannot exceed 50.2025 mm when the closed position is reached.

5. Conclusion

(1) Midas performs the simulation calculation of the longitudinal change in the vertical rotation process of the model. During the lifting process, when the main arch rib is lifted to $6^\circ$, the top displacement of the tower is the most unfavorable state of force, and attention should be paid to strengthen the control when lifting.
(2) The load instability coefficient before the rotation is the smallest, that is, the initial state of the arch rib before the rotation is the most vulnerable state. And it is strictly forbidden to carry out closing construction under strong wind or strong wind conditions.

(3) Carry out the simulation calculation of the horizontal change in the vertical rotation process of the model. During the lifting process of the main arch rib, there may be a certain height difference between the east and west arches. However, the average height difference cannot exceed 114.27mm, and the maximum height difference cannot exceed 50.2025mm when the closed position is reached.

(4) During the construction of the vertical rotation of the main arch rib, the closer it is to the closed state, the more likely it is that the entire force system will be damaged.

(5) The MIDAS model simulates the horizontal height difference of the main arch ribs produced during the vertical rotation construction. Compared with the actual measured height difference, it is found that the calculated height difference of MIDAS is much larger than the measured data, and the height difference range is larger. After inspection and analysis, the MIDAS finite element software is not accurate enough to calculate such ultra-wide and long-span arch bridges, and there are certain errors.

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