The construction technology and simulation analysis of a cable-stayed arch composite bridge

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Abstract. In order to explore the changes of mechanical properties of cable-stayed arch composite bridge in different construction stages, this paper takes a 136m tensed-string arch bridge as the engineering background, briefly describes the construction steps of grid lifting, and adopts Midas/Civil finite element analysis software for modeling. The actual construction process of the arch bridge is simulated by classifying different construction stages. The static and dynamic mechanical properties and stability of arch Bridges are studied. Through research and analysis, the main conclusions are drawn that the cables of the tensioned arch bridge bear part of the load of the original arch rib and girder.

1. Introduction

Cable-stayed arch combination bridge is a kind of new bridge in recent years, compared with the arch, cable can provide more support for arch ring, reduce the negative bending moment of the arch foot, also make the main arch horizontal thrust decreases, and enhance the integrity of the structure of the bridge, the arch of the cross section can be fully used, thus increasing the biggest span arch bridge, can build a larger bridge.

According to their structural systems, cable-stayed arch Bridges can be divided into cable-stayed arch Bridges, tensioned arch Bridge, truncated cable-stayed arch Bridges and so on. [1] In recent years, cable-stayed arch bridge has become the main research target of many scholars for the cable-stayed arch bridge composite system. Yi [2] discusses the influence of the change of the Angle of the cable on the static performance of the cable-stayed arch bridge, and obtains the distribution law of the internal force when the Angle of the cable changes. Wu [3] used finite element software to calculate the natural vibration performance of cable-stayed arch bridge without back cables, and analyzed the natural vibration characteristics of bridge under different cable damage and different damage degree of cables.

As a new type of cable-stayed arch composite bridge, the design concept of tensioned arch bridge is mainly derived from the early large-span roof structure, which is an innovative achievement of composite system. Because its economy is not superior compared with other Bridges, there are not many researches on tensioned arch bridge, and the bridge of this structural system is less applied in China.

Therefore, taking this article as a starting point to a piece of tensioned arch bridge as an example, the key construction techniques were introduced, and in this paper, the finite element model calculation and analysis method of Midas/Civil is established to study the static mechanical
2. Project overview and structural characteristics

2.1. Structural characteristics of tensioned arch bridge
The structural stress of the tensioned arch bridge is between the arch bridge and the cable-bearing bridge. It depends on the arch rib of the upper chord bending and the tension of the lower string to bear the load from the boom. The load of the deck system is transmitted to the tensioned arch by the suspender, and then to the pier by the tensioned arch. The piers bear only vertical loads, not horizontal loads. No resistance to push on the foundation. If there is a Leaning Tower, the force of the lower cable can be transmitted to the Leaning Tower on either side. The arch rib of the upper chord is mainly bending, and its stress condition is complicated, which is related to the shape of the arch rib itself. At the same time, it is related to the line shape and tension of the lower string, and is also closely related to the construction process of the bridge. How to determine the reasonable state of the arch rib is very complicated. The overall mechanical characteristics of the structure are affected by such factors as the span of the arch rib and the linearity of the lower string. [4]

2.2. Project summary
The total length of the main bridge is 136m. The width of the bridge is 11.5m, and the cross-section is arranged as 0.25m (railing) +11m (sidewalk) +0.25m (railing). The main arch adopts 108m upper bearing steel arch, the arch height is 9.2m, and the span ratio is 1/11.74. The section adopts separated steel box section, and the section height is 1.2m. The steel girder of the main bridge adopts welding X-shaped section, the section height is 1.2m, and two sections of the main girder are set up on the beam of the main tower. The arch foot is connected to the concrete arch base by a PBL shear key. The cable tower adopts cast-in-place concrete tower with variable section, and the height of the tower is 13.04m.

The cable tower adopts cast-in-place concrete tower with variable section, and the Angle between the plane where the main cable and back cable is and the vertical plane of lead is 12°. PES (C) is used in the main line 7-223 product line, the top main cable anchorage on the bridge tower, through the locator to wear under the arch rib, using poles and arch rib are linked together, form a set of string arch, the bridge of the two main cable of two groups of string arch, back line with PES (C) 7-121 product line, cable support the top back on the bridge tower, the bottom through the ear plug and anchor plate connection, Anchor to bearing platform. D150cm bored cast-in-place pile is used as foundation. As shown in figure 1

![Overall layout of bridge.](image-url)

3. Construction plan
The construction of the bridge focuses on segmental hoisting and hierarchical tensioning. The construction steps are as follows:
(1) Construction of partial rerouting of dyding road. Site leveling, clearing out the working face, pile foundation construction. Excavate foundation pit, pour concrete of cap and arch. After the concrete reaches the strength requirement, the foundation pit is backfilled.

(2) erecting support and pouring concrete of bridge tower. Pour the concrete of the beam between the towers. The steel structure arch foot segment is positioned and the arch foot concrete is poured.

(3) Erection of construction bridge. The steel arch section was hoisted symmetrically into 6 sections in turn, and the mid-span closing section was finally hoisted and assembled on site.

(4) Set up the upper column and main beam of the arch in sequence, and carry out the auxiliary works construction.

(5) Remove the steel bridge and remove the temporary support of the arch ribs. Then the main line is erected and the back line is installed. Single main cable tensioning force is 2500kN, and single back cable tensioning force is 550kN. Stretch the main cable and back cable by stages, and stretch the main cable and back cable in sequence. Finally, remove the pylon supports.

(6) Pouring the top of the tower to seal the anchor section. Bridge construction and operation.

4. Finite element analysis
Madis/Civil was used to build the finite element analysis model. Among them, the main arch, main girder and main tower are simulated by beam element, the cable is simulated by tension-only truss element, and the support is simulated by press-only spring. The bridge has a total of 443 nodes and 400 units. Loads considered include dead weight, cable force, phase II pavement and pedestrian load. The finite element model is shown in Figure 3.
4.1. Static analysis

In different construction stages, the stress and displacement generated by the arch ribs of the arch bridge are also different. In the finite element analysis, construction stages worthy of study should be selected for study, such as the construction stages involving system transformation and boundary condition changes, such as segmental hoisting of arch ribs, dismantling of arch supports, hierarchical tensioning of cable cables and dismantling of cable tower supports.

During the segmental hoisting of arch ribs, since there are many stages, one of the steps is selected for analysis, and the stress and displacement diagram of the step is shown in Figure 4. It can be seen from the figure that the compressive stress near the arch support is large and the maximum can reach -9.924MPa; the tensile stress in the middle of the arch segment is the maximum and the maximum can reach 3.077MPa; the stresses in other parts are small and all meet the steel strength requirements. The cable tower made of C40 concrete has the maximum stress of -0.1MPa, which meets the requirement of concrete strength. Investigate the reason, in the construction, in order to ensure safety, the arch rib and tower under the bracket are erected.

![Strain and Displacement Diagram](image)

Figure 4. Stress and displacement diagram of an arch rib in a certain step during hoisting stage.

Before the removal of the arch supports, the main structure of the bridge was completed by construction except for the cables. When the structure is dismantled, it will undergo the system transformation from the boundary condition change, and the stress and displacement of the structure will have a great change. The stress diagram and displacement diagram before and after demolition are shown in Fig. 5 and Fig. 6. It can be seen from the figure that, before the removal of the arch support, the maximum compressive stress appears on the column at the most edge of the arch beam connection, which is -13.167MPa, and the maximum downward deflection appears on the main beams on both sides, which is 2.678mm. After the removal of the arch support, the maximum compressive stress is -31.818MPa at the arch foot, and the maximum down flexural displacement is 22.77mm in the middle of the span.

From this analysis, it can be concluded that the stress and displacement change after the boundary conditions change. There is no doubt that a large downward-bending displacement caused by the dead weight occurs in the middle span of the arch rib after the support is removed. The change of the maximum compressive stress is due to the change of the structure from the original stress state of segmental construction with brackets to the natural stress state of the arch bridge, and the compressive stress of the arch foot increases accordingly, and the arch foot becomes the position of the maximum compressive stress of the whole bridge.
After the arch support is removed, the construction stage of cable tensioning is carried out. According to the construction plan, the cable is divided into two stages of tensioning, the main cable and back cable are alternately tensioned, and the classification is 80% of the first stage tensioning and 100% of the second stage tensioning. The stress and displacement diagram in the tensioning process is shown in Figure 7 and Figure 8. As can be seen from the figure analysis, the stress of arch rib and cable tower does not change much during the tension process, and the mid-span down flexural displacement gradually decreases from 25.613mm before the tension to 22.178mm.
4.2. Dynamic characteristics and stability analysis

For the structure, its dynamic and mechanical properties are controlled by the natural vibration frequencies and vibration shapes of the first several modes of the structure [5]. In this paper, the Lanczos iterative method of Midas/Civil was used to solve the natural vibration characteristics of the first three orders of the structure. The natural vibration frequency and mode characteristics are shown in Table 1, and the modal diagram of the orders is shown in Figure 9.

Arch bridge is a composite structure arch bridge whose linear elastic stability coefficient is more complex. Therefore, this paper adopts the linear elastic stability theory of the first kind to calculate the stability safety factor $K$, and analyzes whether the stability of the first three order buckling modes meets the requirements (stability safety factor $K > 4$). The $K$ values of the first 6 orders are shown in Table 1.

### Table 1. Frequency, mode characteristics and $K$ of the first three order natural vibrations

| Order | Natural vibration frequency (Hz) | Mode characteristics | $K$  |
|-------|---------------------------------|----------------------|------|
| 1     | 2.031                           | Transverse antisymmetric bending | 66.14|
| 2     | 2.041                           | Transverse symmetric bending | 106.9|
| 3     | 2.317                           | The arch ribs are transverse and antisymmetric | 110.2|

From this analysis, it can be concluded that the safety factor $K$ of the bridge is greater than 4, which meets the stability requirements.

5. Conclusions

The following conclusions can be drawn from the finite element analysis of the long-string arch bridge:

1. the force of the bridge is uniform and reasonable, and all parts of the structure meet the strength requirements, and meet the practical application needs.

2. in the construction process, with the change of boundary conditions caused by the system transformation, the bridge stress and displacement have a great change, but in the whole construction process of the bridge, the stress change is not large, in the normal and reasonable range.
3. With the tension of the cables, the stress and downward-bending displacement of the arch bridge gradually decrease. As a special tensioned arch bridge, the cables effectively bear part of the load originally borne by the arch ribs and main girder.
4. The safety factor $K$ of all orders of the bridge is greater than 4, satisfying the stability requirements.

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