Comparison of Hangers’ Tensioning Sequence of Diagonal-span Arch Bridge

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Abstract: The Diagonal-span arch bridge is novel in shape and complicated in force. In order to ensure the safety of the bridge during the tensioning of the hanger, Midas Civil was used to establish a three-dimensional finite element model and four kinds of tensioning scheme are compared. This study analyses the deformation and stress of arch rib, girder and hangers to determine a reasonable tensioning sequence. The results show: On the basis of satisfying the lateral stability of the arch rib, the tensioning sequence from the two sides to the middle have the smallest stress and reasonable deformation. This study can provide reference for similar bridges.

1. Introduction
With the development of society and the increasing emphasis on bridge aesthetics, some novel shaped arch bridges are increasingly used in landscape bridges. Different from general arch bridges, the arches are arranged obliquely with the beams, the arches are cambered or the arch ribs are skewed, and the booms are arranged at the same slope, which makes the profiled arches have a unique dynamic effect in proportion [1]. The special-shaped arch bridges built in recent years include Anyang Dongfeng Bridge [2-3], Harbin Inner Ring Road East Kuancheng Bridge [4], Tianjin Dagu Bridge [5] and so on. The diagonal-span arch bridge has a unique structure and a beautiful appearance, and has become a competitive bridge type in the special shaped arch bridge [6].

Due to the unique structure and complex stress of diagonal-span arch bridge, adverse working conditions may occur in the process of hanger tensioning. It is necessary to check the process of suspender tension in order to ensure the safety of force and smooth alignment of the bridge. Based on the engineering background of a cable-span arch bridge, the hanger tension is simulated and analyzed by finite element method, which provides theoretical guidance for stress and deformation monitoring in the whole tension process, ensures the safety of the bridge in the tension process, and meets the design requirements after the completion of the bridge.

2. Project

2.1. Project Overview
The main span of the background bridge is 95m. The arch ribs straddle the main girder, and its span is 90 m and rise-span ratio is 1/3. The arch beams have 12 pairs of hangers. The longitudinal slope of girder is 2%. The main girder adopts a separated 3 box girder with a beam height of 2 m and a full width of 19 m. The arch rib has an equal section along the arch axis. The spacing of the hanger on the arch is 1.5 m and that on the girder is 3 m.

2.2. Tensioning scheme of the Hanger

Different tensioning schemes have different effects on the bridge. In order to analyze the force of the bridge during the tensioning process, four tensioning schemes are designed. The tension sequence of scheme 1 is tensioned from the middle to the two sides; the tension sequence of scheme 2 is tensioned from the two sides to the middle; the tension sequence of scheme 3 is tensioned alternately on the two sides and the middle; the tension sequence of scheme 4 is tensioned from the one side to the other side. The specific tensioning scheme is shown in Table 1, and the number of hangers is shown in Figure 1.

Table 1. Tensioning scheme

| Step  | Scheme 1 | Scheme 2 | Scheme 3 | Scheme 4 |
|-------|----------|----------|----------|----------|
| Step 1 | A6,A7,B6,B7 | A1,A12,B1,B12 | A6,A7,B6,B7 | A1,A2,B1,B2 |
| Step 2 | A5,A8,B5,B8 | A2,A11,B2,B11 | A1,A12,B1,B12 | A3,A4,B3,B4 |
| Step 3 | A4,A9,B4,B9 | A3,A10,B3,B10 | A5,A8,B5,B8 | A5,A6,B5,B6 |
| Step 4 | A3,A10,B3,B10 | A4,A9,B4,B9 | A2,A11,B2,B11 | A7,A8,B7,B8 |
| Step 5 | A2,A11,B2,B11 | A5,A8,B5,B8 | A4,A9,B4,B9 | A9,A10,B9,B10 |
| Step 6 | A1,A12,B1,B12 | A6,A7,B6,B7 | A3,A10,B3,B10 | A11,A12,B11,B12 |

2.3. Finite element model

Full-bridge has 383 units and 286 nodes. The girder and the arch rib are built by the beam unit, and the truss unit is used to establish the hanger. The hanger is elastically connected to the girder and the arch rib. The arched foot is fully consolidated and the girder is constrained by a simply supported beam. The load includes the weight, the second stage load, and the girder pressure weight.
3. Result analysis

The following analysis mainly analyzes the deformation and stress of the arch rib and the girder to find the reasonable tension sequence which can ensure the safety of the bridge during the construction.

According to Fig. 3, the maximum tension of hanger is 1115 kN, the maximum tension is 1236 kN in scheme 2, the maximum tension of the scheme 3 is 1200 kN in scheme 3, and the maximum tension of the scheme 4 is 1048 kN in scheme 4. Scheme 4 is optimal, and the maximum tension of hangers is reduced by 18% compared to the most unfavorable scheme 2.
According to Fig. 4 and Fig. 5, a large lateral deformation of the vault in scheme can reach 220mm, which is not conducive to the linear control of the arch rib, and seriously threatens the safety of the bridge. The deformation in the scheme 1 is the minimum, and the maximum lateral deformation is only 5 mm. The maximum deformation in scheme 2 is 0.04m, and the maximum deformation in scheme 3 is 255mm. The maximum vertical deformation of vault in scheme 1 is 44.15m, that in scheme 2 and scheme 3 is 43.78m and that in scheme 4 is 43.9mm.

According to Fig. 6, scheme 2 is the optimum scheme, and the maximum stress is about 100 MPa. The maximum stress of scheme 1 and scheme 4 is about 116 MPa, and that of scheme 3 is 104 MPa. The stress of scheme 1 is 16% less than that of scheme 2 and 4, and 4% less than that of scheme 3.

According to Fig. 7, the vertical deformation of girder in the middle of span.
As shown in figure 7 and figure 8, the influence of different tension sequence on the main girder is basically the same. So, the influence of the girder can be omitted.

In summary, the scheme 4 is optimal in the tension of the hanger. But the lateral deformation caused by scheme 4 is too large, which is not conducive to the control of the arch rib alignment. The lateral deformation in scheme 1 is the smallest, but its stress on the vault is larger, which is not conducive to the safety of the arch ribs. The deformation of the vault produced by scheme 2 is slightly larger, but the stress of the vault is smaller, which is beneficial to the safety of the bridge. Therefore, on the premise of satisfying the lateral stability of arch ribs, the tension sequence from the two sides to the middle is safer.

4. Conclusion
The tensioning sequence from the middle to the two sides produces less lateral deformation, but a greater stress is generated in the vault. The lateral deformation of the vault of the tensioning sequence from the two sides to the middle is slightly larger, and the stress generated in the vault is smallest, which is beneficial to the safety of the bridge. On the basis of satisfying the lateral stability of the arch rib, the tensioning sequence from the two sides to the middle is recommended.

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