Design of an arch bridge with spatial-triangle-ribs

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ABSTRACT: A new type arch bridge is described, which is a half-through arch bridge with spatial-triangular-ribs formed by two arch ribs in one side and a single arch rib in the other side and merged near the crown. This simple but unique configuration of the structure can have a special aesthetic effect and can make the bridge more attractive to people and more harmonic to a special environment. Taken such a type bridge with a span of 280m as an example, the structural design, selection of arch axis, buckling analysis and construction method are introduced.

1 INTRODUCTION

Arch bridges are always attractive by its natural and nice appearance. With the development of technology and material, more and more innovative arch bridge appeared and arch bridge becomes a bridge with various structure forms and rich in appearance (Gao 2005). One of them is an arch bridge with spatial-triangular-ribs, which is formed by two arch ribs in one side and a single arch rib in the other side and merged near the crown. This type bridge has been adopted in pedestrian bridges or highway bridges with short spans (Yang 2000).

In an open design competition, we proposed an arch bridge with spatial-triangle-ribs with a span to 280m. As shown in Fig.1, a half-through arch bridge can give a good appearance and coordinates with the surrounding environment. However, the road in the right bank is closely to the side of the bank and the intersection will interpose into the bridge, so it is difficulty to arrange two arch ribs in this side, instead, a single rib arch is a good solution. But a single arch rib will take a certain width of the bridge and it is weak in the out-of-plane stability. In the other hand, in the left bank there is enough space for an intersection and two arch ribs. Therefore, an arch bridge with spatial-triangle-ribs was proposed for both economic and aesthetic reasons (Fig. 1), in which one rib in one side was used for the space limitation and two ribs in the other side was used to provide high stability capacity and a beautiful appearance.

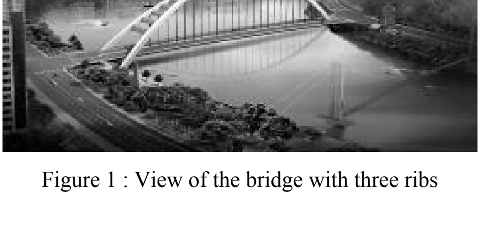


Figure 1 : View of the bridge with three ribs

2 STRUCTURAL DESIGN

The total length of the bridge is 299.3m with a width of 32.5m. The calculated span is 280m, and the calculated rise is 70m, giving a rise-to-span ratio of 0.25. Two arch ribs at the left bank merged into one rib in the section 110m from the spring at the left bank as shown in Fig. 2.

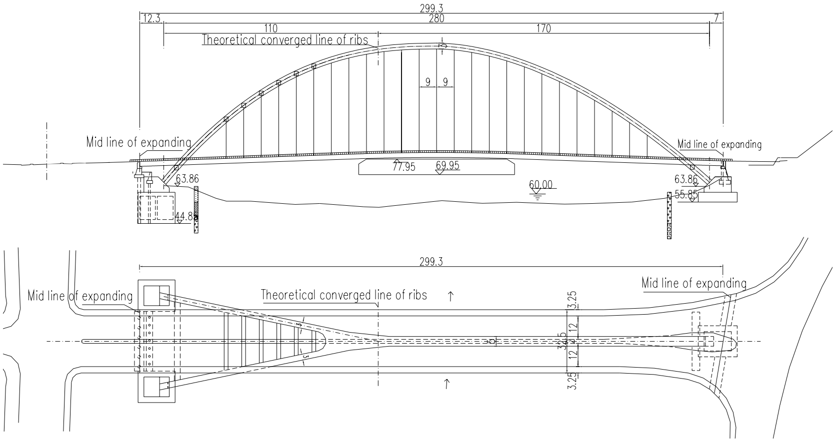
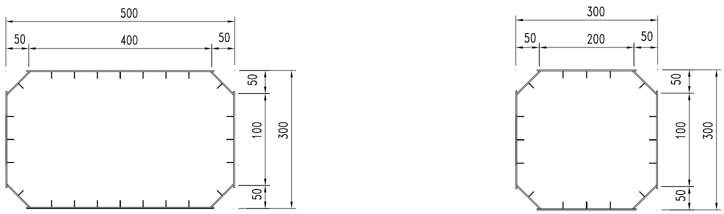


Figure 2 : General layout of bridge (Unit: m)

The arch ribs are made of welded steel boxes height of 3m, the width of the single rib in right side is 5m and the width of each rib of the double ribs in left side is 3m, as shown in Fig, 3.



a) Main arch rib b) Branch arch rib

Figure 3 : Typical section of arch rib (Unit: cm)

The stiffened deck girder is in steel box section with an orthotropic plate in top slab. It has a height of 2.5m and the width of 32.5m, see Fig. 4.

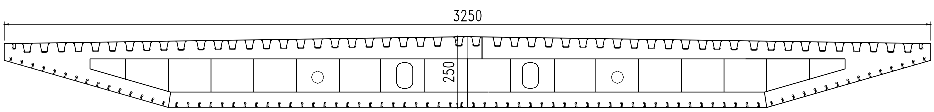


Figure 4 : Section of main girder (Unit: cm)

There are 25 pair hangers with a spacing about 9m to hang the deck girder in the central line as a single cable plane. Two hangers composed a pair with a distance of 1m in transverse to provide torsional capacity of the deck girder and reduce anchorage dimensions as well as beneficial to the later cable replacement. The girder is divided into two in the right end above the single rib and support on the brackets extended from arch rib.

3 STRUCTURAL ANALYSIS

3.1 Finite Element Model

A spatial finite element model is established to calculate and analyzes the preliminary design of the bridge. The arch ribs, bracings and the stiffened deck girder are modeled by spatial beam elements and the hangers by cable elements. The finite element model shown in Fig. 5 has 177 spatial beam elements, 25 cable elements and 177 nodes in all.

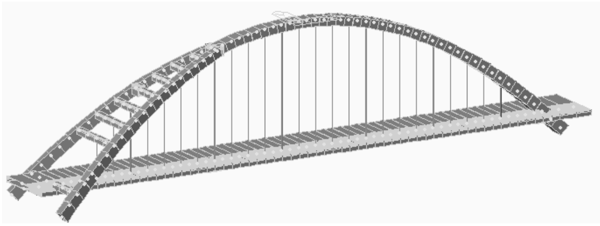


Figure 5 : Finite element model

3.2 Selection of Arch Axis

The arch rib is usually shaped to take dead load with the smallest bending moments and even without bending moments if it is possible. A spatial-triangle-ribs arch is a special kind of arch structure, therefore it is doubt that if the curves generally used in arch axis is propriety in it, such as the centenary, the parabola as well as circle curves.

At first, a symmetrical quadratic parabola was assumed as the axis curve to check if it was a propriety curve. The bending moments in the arch rib of such an axis were calculated as shown in Fig.6. From the figure it can be seen that the bending moments in the arch rib member is unsymmetrical and the maximum one is 61622kN-m at arch spring of the right side. Therefore, a symmetrical secondary parabola curve is not reasonable to be the arch axis, while the unsymmetrical one should be adopted.

Figure 6 : Distribution diagram of arch rib moment in built bridge period (Quadratic Parabola)

In order to eliminate the bending moments under dead load, a try-and-error method was used to select the arch axis curve. The calculation process is shown in Table 1. As a selection result, $y = x^{2.4}$ parabola was adopted for the arch axis on the left side with two separated arch ribs and $y = x^{1.8}$ parabola was adopted for the arch axis on the right side with a single arch rib.

Table 1 Moment of various sections of arch ribs in built bridge period(Unit: KN.m)

Section / Parabola	Arch spring on left side	Left side L/4	Mid-span	Right L/4	Arch spring on right side
Left $y = x^2$, right $y = x^2$	-36751	25273	-8857	13346	61622
Left $y = x^{2.2}$, right $y = x^{1.9}$	-18638	13903	-3965	-2517	31420

Left $y = x^{2.4}$, right $y = x^{1.8}$	11760	8656	-7800	8721	-6304
Left $y = x^{2.6}$, right $y = x^{1.7}$	49816	-3715	-4797	19802	-32343

The bending moments distributed in the arch ribs shown in Fig. 7 is much smaller than those in Fig. 6. The maximum moment at arch spring on the left side is 11760kN.m, its absolute value is only 32% of that in Fig. 6.

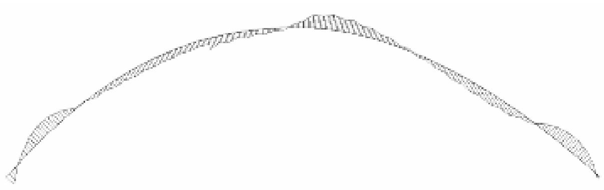


Figure 7 : Moment distribution diagram of arch rib in built bridge period (left $y = x^{2.4}$, right $y = x^{1.8}$ parabola)

3.3 Stability Analysis

The first to fourth Eigenvalue buckling modes of the bridge subjected to dead loads, traffic loads and the pedestrian loads is shown in Fig. 8 to 11. Their corresponding critical load factors are listed in Table 2. The design load was based on the Chinese Standard of Loadings for the Municipal Bridge Design (CJJ 77-98).

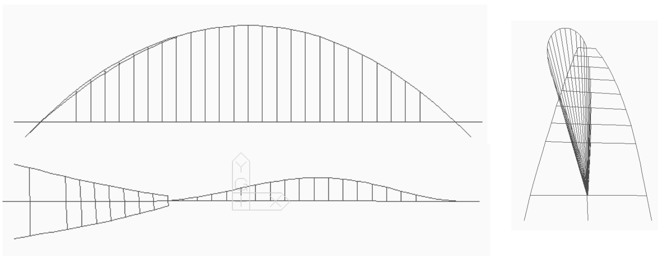


Figure 8 : The first Buckling mode

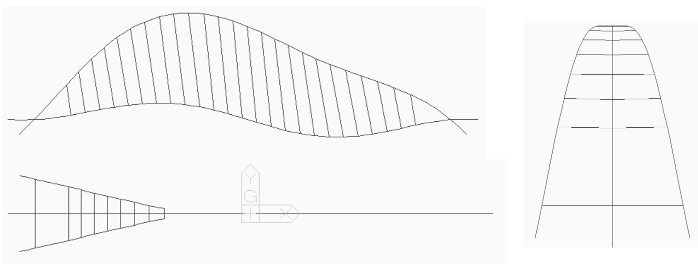


Figure 9 : The Second Buckling mode

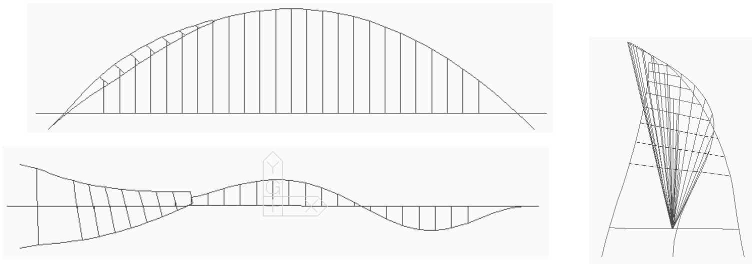


Figure 10 : The Third Buckling mode

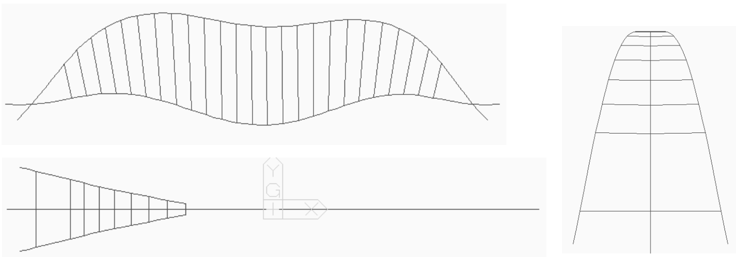


Figure 11 : The Fourth Buckling mode

Table 2 Critical Load Factors

Mode	Critical Load Factor	Buckling Mode Shape
1	9.68	Out-of-plane
2	14.77	In-plane
3	15.61	Out-of-plane
4	21.58	In-plane

From Table 2 it can be known that the critical load factor of the first mode is 9.68 and it can satisfy the design requirement. From Fig. 8 and Fig.10 it can be seen that both of the first and the third buckling modes are out-of-plane. In the first mode, the single rib deforms in out-of-plane in a symmetric shape while in the third in a asymmetric one. It is obvious that the single arch rib's buckling dominate the global buckling of the structure and the two ribs in the other side take an important role in stability of the structure.

The second and the fourth buckling modes shown in Fig. 9 and Fig. 11 indicate the first two in-plane buckling modes, i.e., asymmetric and symmetric shapes, are similar to normal arch structures. In other words, the in-plane buckling modes do not affected by the special structure components, i.e., spatial-trial-rib structure.

4 CONSTRUCTION METHOD

A construction method is proposed to such a special structure in design according to the bridge site condition. A cable crane can be used as the hoisting method. The two ribs in the left side will be fabricated on scaffoldings and rotated vertical into position and the single rib will be erected by cantilever launching method directly. The schematics of the arch construction is shown in Fig. 12.

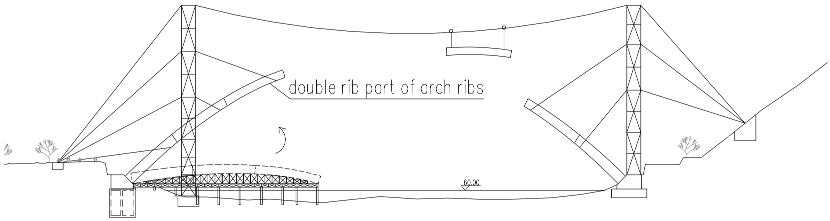


Figure 12 : Schematics of Arch Construction

After the closure of the arch ribs, the segments of the deck steel girder in box section are transported to place under the arch ribs and hoisted into decking position by the cable crane from two sides to the mid-span in a proper order. Each segment is hanged to the arch rib by cable hanger and the adjacent segments are fixed by temporary bracing. After all the segments of box girder are erected, they are welded together to form a design stiffened deck girder.

5 CONCLUSIONS

An arch bridge with spatial-triangle-ribs is a new type arch bridge which can be good looking and can be a suitable type to some special topography. Analysis of such bridge with a main span of 280m indicates that in order to eliminate the bending moments under dead load, asymmetric arch axis should be adopted. The out-of-plane buckling modes of such a bridge is different to a normal one, in which the single arch rib's buckling dominate the global buckling of the structure and the two ribs in the other side take an important role in stability of the structure. But the in-plane buckling modes are not special, which is same as other type arch bridge.

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