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ERECTION ANALYSIS OF THE CFST ARCH BRIDGE BY VERTICAL SWING METHOD OVER THE JING-HANG CANAL IN XUZHOU, CHINA

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Abstract. *A CFST arch bridge over the Jing-Hang Canal in Xuzhou, China, is a tied arch bridge with triple spans of inclined ribs. The truss CFST arch rib is the central span of 235m, which was erected by the vertical swing method. This paper uses a general purpose finite element software SAP to analyze the behaviors of the erecting structure including the erected half span of the hollow steel tubular arch and the temporary stable, towers, etc. The analysis results, such as the relationship curve between the internal force of cable and angle of erection, will provide guidance for construction.*

1 INTRODUCTION

A CFST arch bridge over the Jing-Hang Canal in Xuzhou, China, is a tied-arch basket bridge with triple spans. It is the key projects in the national highway trunk linking the east coast to the west side of China, from Lianyungang in Jiangsu Province to the Huoerguosi in Xinjiang. The truss CFST arch rib is central span of 235m; the side span of reinforced concrete half cantilever arch is 57.5m (Fig. 1). The bridge is a lifting-basket arch bridge with a inclination of a 80° 03′ 57.6 " in the main span and 79° 52′ 39.9 " in the side span.

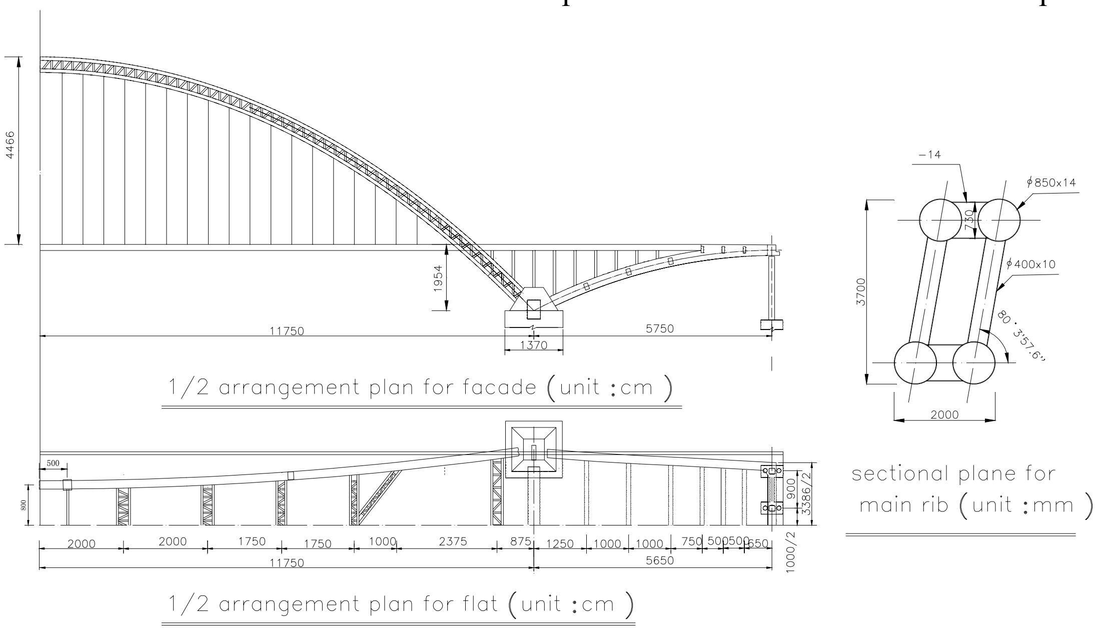


Fig.1 Elevation of main bridge

The erection of an arch bridge encounters more difficult problems than a girder bridge, especially when it is made of masonry and concrete. An important advantage of the CFST arch bridge is that the hollow steel tube arch itself can be erected with lighter self-weight and more outstanding stiffness than the concrete member or shaped steel member. For the Jing-Hang Canal Bridge in Xuzhou with a span of 235m, it is not difficult to be erected by cable crane method if the ribs are parallel. However, it is a tilt-basket arch and the tilt arch rib makes it very difficulty to erect by that method. Therefore, a vertical swing method is used in the erection of the bridge.

The vertical swing method used in erection of reinforced concrete arch bridges began from 1970's in China. This method is also applied and developed in CFST arch bridges[i,ii]. The swing method includes the vertical swing method and the horizontal swing method. In the vertical swing method, two half leaves of ribs on vertical hinges at arch seats at ground level to save falsework are erected and rotated vertically into closure position with hydraulic jacks. The largest CFST arch bridge-Yajisha Bridge in Guangzhou City used both the horizontal swing method and the vertical swing method.

A CFST arch rib was fabricated in plan and translated to the site by ship in several segments. They are assembled into half rib in the falsework in the river. In order to ensure the safe and provide guidance for erection, finite element analysis of the swing unit has been carried out. A swing unit includes a half steel tubular arch, the temporary stayed cables and the tower. Two swing units have been successfully erected in June 29 and July 6, 2001 respectively. The bridge was opened to traffic in 2002. The calculation results agree well with the measurement data in erection.

2 FE MODEL

A three-dimensional linear finite element model has been developed by using SAP93, a finite element analysis software and shown in the Fig. 2. The model includes main arch rib, tower and drag cables and stayed cables.

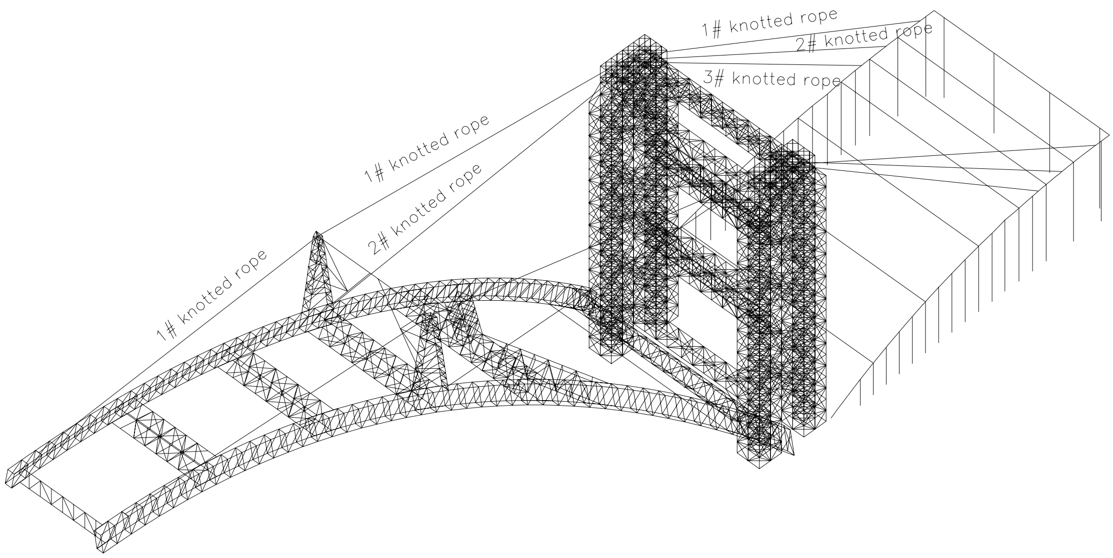


Fig.2 Finite Element Model

The section of the main truss CFST arch rib of the Jing-Hang Canal Bridge in Xuzhou is shown in Fig. 1. The rib is a two-dumbbell type section composed of two horizontal dumbbells connected with web bars vertically. All of the tube members, including the four CFST chords, steel tubular web members in a rib as well as bracing members are modeled by beam elements. The horizontal plates connected two CFST chords at the same level are simulated by shell elements.

At the initial analysis, the cable nonlinear behavior was considered by using a correction elastic modulus[iii]. The calculation result showed that the cable non-linearity influence to the structure behaviors is very small and can be ignored, because the large pulling force in the cable make the cable like a bar. Therefore, in the formal finite element model, the cable is simulated by space beam element with a very small flexural rigidity EI and a very large compressive rigidity. A rod is added in the model to connect the cable and the saddle. The two angles between the cable and the rod are the same. In this way, the calculated forces of the cable in two sides of the saddle can be equal to actual value (Fig. 3).

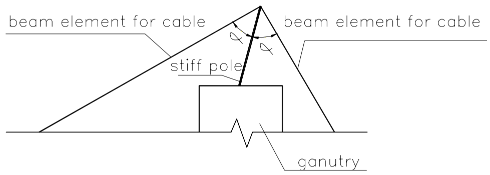


Fig.3 FE model in saddle

The arch rib of the main span is hinged to the arch seat. The arch rib of the side span and the tower are fixed to the arch seat and pile cap, respectively. During erection of main span rib, the rib of the side span lay on the falseworks has a tendency to move up, but the support can only carry the compressive force but not tensile force. So cables were used to connect the end of the rib of the side span and the falsework to prevent the upward movement of the rib.

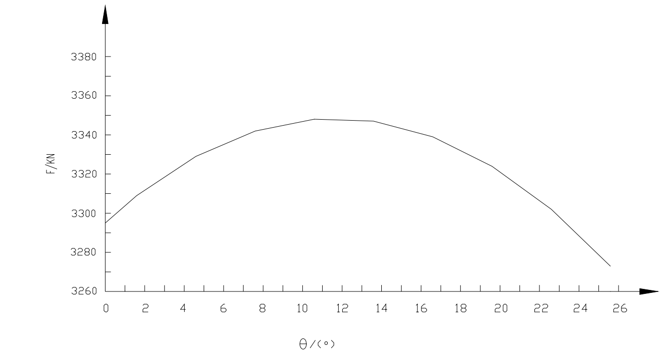
The arch rib of the main span should rotate a vertical angle from 0^0 to 25.5942^0 to its closure position. In calculation, the total rotation process is divided into 10 stages to analyze. At the first stage, the angle is 0^0 (the arch rib is laid on the falseworks before pulling up). The angle is 1.5942^0 for the second stage, and 4.5942^0 for the third stage, 7.5942^0 for the fourth stage, etc., the angle for the next stage is 3^0 larger than the former one.

3 RELATIONSHIP CURVES OF CABLE FORCES AND VERTICAL SWING ANGLES

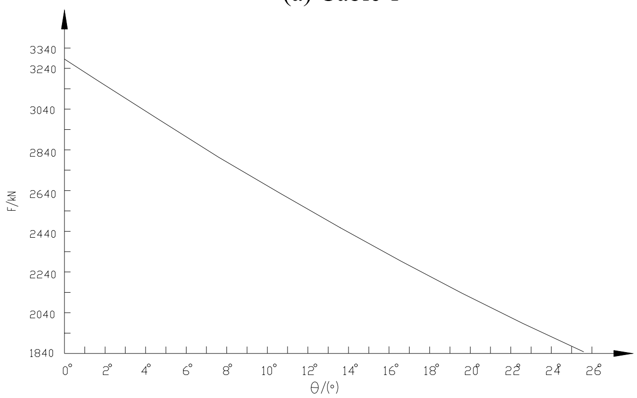
The relationship curves of cable forces and vertical swing angles are very important in the construction and design. These curves will be used to guide the work of the hydraulic jack system during vertical swing process. The curves from the calculation are shown in Fig. 4.

The cable 1 and cable 2 are the drag cables. The curve of Cable 1 is similar to a parabola curve. The cable force at the begin and end of the swing procedure is 3295 kN and 3273 KN, respectively. It reaches to the peak value of 3348 kN when the angle is 11.5942^0. The force of Cable 2 decreases from the beginning of 3286 kN to the end of 1848 kN. The cable 3 is only an equilibrium cable to ensure the stability of the tower and improve the force distribution of the side arch rib. The curve of the Cable 3 is similar to that of the Cable 1. The force of Cable 3 is 786 kN and 861 KN at the begin and end of the swing procedure, respectively. It reaches to the peak value of 992 kN when the angle is 13.5942^0.

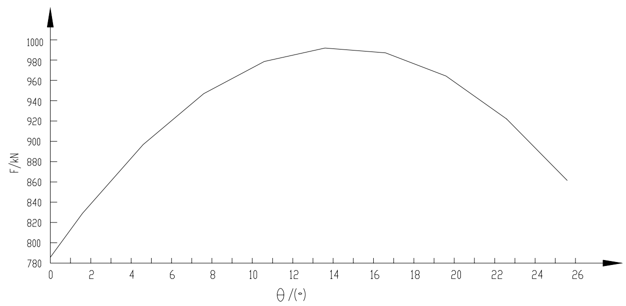
The relationship curves of cable forces and vertical swing angles result from the calculation can be used in the design of lifting and control of jack system. However, the cable forces will be influenced by many factors which are not be possible to consider in the calculation. So monitoring of measurement and control is necessary to modify the cable force in the swing procedure.



(a) Cable 1



(b) Cable 2



(c) Cable 3

Fig. 4 Relation curves of cable forces and vertical swing angles

4 STRESSES AND DEFORMATIONS OF THE ARCH RIBS

Friction between lifting cable and tower is not considered in the FE analysis. The compressive stress is assumed as negative and tensile stress positive. The deflection in vertically up direction is positive and in vertically down direction is negative.

4.1 Stress

At the beginning of the rotation, the largest compression and tension stress of the chord member in the main arch rib is 47.34 MPa and 20.34 MPa at the quarter section, respectively.

At the end of the rotation, the largest compression stress is -52.37 MPa at L/8 section as the maximum one during the rotation; however largest tension stress is only 4.1 MPa at the crown section. The largest tension and compression stress of web members are 48.06 MPa and -82.69 MPa nearby the quarter section, respectively. The stress of steel tubular arch during rotation is much smaller than the allowable stresses of 210 MPa for the chord members and 145 MPa for other members.

The stresses of the RC arch rib of side span decrease from beginning to end of the rotation. The largest compression stress is -3.053, smaller than the standard design compression strength 28.5 MPa of the concrete. The largest tension stress is 1.747MPa, slightly exceeds its allowable strength 1.45 MPa. Some measurements can be used to reduce the tensile stresses, such as setting a temporary tension support at the end of side arch rib; strengthening the reinforcing bars or pre-stress a temporary cable in the area where the stress exceeds the allowable strength; optimizing the position of cable 3 or adding another equilibrium cable.

Wind loads are major component of lateral loads that act on the bridge structure. The wind effects may be divided into: static wind pressures, dynamic wind movements and buffeting between adjacent structures. However, because the erection time by swing method needs only a day for a unit, so it is possible to choose a day without large wind to carry out the erection. Therefore, only the static wind pressures are considered in the erection analysis. The calculation results shows that the wind loads are not critical to the erection. The total wind force acted on the structure is only 47 tons and the stress of the structure is smaller than the allowable stress of steel.

4.2 Deformation

The deflection of the arch rib in main span is in vertically downward. The maximum deflection is at nearby 3L/8 section with the value of -0.0802m at the end of the vertical rotation of main arch rib. When the two half arch ribs are closed, compared to the standard two hinge arch, the axis of the rib is higher with a maximum difference of 0.0228m at the crown and lower with a maximum difference of 0.0145m at the spring section. The deflection occurred in the erection of swing process should be considered during fabrication and assembly of the segments into arch rib at the falsework, in order to guarantee the design arch axis.

The deflections of the main arch rib are much larger than those of the side arch rib as well as the tower, for side arch rib and tower have larger rigidities than the main arch rib. The largest vertical up and down deflection of side arch rib is 0.00435m and -0.0006m, respectively, at the beginning of the vertical swing. These two values will change to 0.00257m and -0.0007m, respectively, at the end of the vertical swing. It shows a trend of pulling up of the side arch rib. Therefore, it is suggested to set a temporary tension support at the end of side arch rib to prevent it from pulling up.

5 ELASTIC BUCKLING ANALYSIS OF TOWER

The tower is predominantly a compression structure. The elastic buckling analysis of the tower shows that at the time the vertical swing started, the safety factor of elastic buckling of the tower is the smallest compared it to other time. However, it is as high as 52.13, much larger than the generally requirement value of 4-6.

6 CONCLUSIONS

- During vertical swing procedure, the stresses and deformation of the main arch rib are small, and the safety factor of elastic buckling of the tower is very large. So in general, the vertical swing method is appropriate and safe for the Jing-Hang Canal Bridge in Xuzhou.
- The forces of drag cable 1 and 2 vary with the swing angle. The relationship curves of cable forces and vertical swing angles result from the calculation can be used in the technological design of lifting and control of jack system. However, the cable forces during construction will be influenced by many factors which can not be predicted and calculated. So, monitoring of measurement and control is necessary to modify the cable force in the swing procedure.
- The side arch rib is a curved reinforced concrete beam during the vertical swing procedure. It has a tendency to be pulled up and its stress exceeds the allowable concrete tensile strength. Some improvement measurements should be taken into account, such as setting a temporary tension support at the end of side arch rib; strengthening the reinforcing bars or pre-stressing a temporary cable in the area where the stress exceeds the allowable strength; optimizing the position of cable 3 or adding another equilibrium cable.
- There is difference in arch axis between the standard two-hinge arch and the arch rib form by vertical swing method. This difference should be considered in fabrication and assemble of the arch rib.

REFERENCES

[i] Chao Sun, Baochun Chen, Youjie Chen, Swing Method of CFST Arch Bridge Construction in China, Proceedings of the 10th Civil Engineering Conference, 515～519 (2001)

[ii] Zhang L. and Chen J., Application and Development of the Rotation Construction Method of Arch Bridge in China, Arch'01 (Third international arch bridges conference), Paris, 883-888 (2001)

[iii] Debiao Ning, Huibin Wu, Erection Analysis of Ya Jisha Arch Bridge by Vertical Swing Method in Guangzhou, Supplement of Engineering Mechanics, 351～355 (1999)

[iv] Jianguo Tang，Biaocheng Xiang, Renfu Xiao, Construction Technology of the Third Bridge over the Guijiang River by Vertical Swing Method, Proceedings of the 14th Bridge and construction Engineering of Civil Engineering Conference, Tongji University Publishing House, Shanghai, 368～372 (2000)