Rigid-frame tied through concrete filled steel tubular arch bridge

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ABSTRACT**:** Rigid-frame tied through arch bridge is brought into use with the application of concrete filled steel tube (CFST) arch bridge in China. Development of such bridge type is introduced with some typical bridges. The major issues in design on the structure and the erection are presented. Calculation equations for inner forces of the structure under dead loads are obtained by displacement method.

1 INTRODUCTION

The rigid-frame tied through arch bridge is a main type in CFST arch bridge. Generally, it is a single-span bridge as shown in Fig.1. The arch ribs are fixed to the piers to form a rigid frame. High strength strands are employed as tied bars by pre-stressed to produce horizontal compression forces to balance the thrust of the arch ribs.

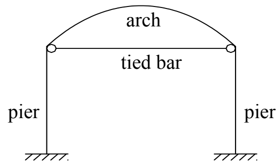


Figure 1: Rigid-frame tied through CFST arch bridge

This bridge structure was proposed in the first CFST arch bridge in China, i.e., Wangcang Donghe Bridge (Fig.2), which was opened to traffic in 1990. The bridge carries four lanes with a width of 15m and has a main span of 115m. The arch rib has a rise-to-span ratio of 1/6 with a 2m high dumbbell cross-section, which consists of two CFST tubes and two steel webs as well as the filled concrete. The floor system is reinforced and piers are reinforced concrete structures. A D-250cm cast in-situ pile carry the pier column as its foundations. The arch rib was erected by cantilever method with cable crane.

Due to the lower cost of substructure and foundation than true arch and the easy erection compared to tied arch, many such bridges have been built after Wangcang Donghe Bridge. Statistics analysis shows in the 232 built CFST arch bridges in China, 30 of them are rigid-frame tied through arch bridges (Chen Bao-chun, 2007).

The span of such bridge form is generally 80m - 150m. It can reach a large span without side span, as necessary in continuous girder bridge or cable-stayed bridge. Therefore when only a main long span is needed to cross a railway or highway, a rigid-frame tied through CFST arch bridge can be a viable economic solution, such as the Beizhan Bridge (Fig.3) located in Guangdong Province. It crosses over 29 rails of a railway with a span of 150m and clear width of 23.5m. The rise to span ratio of the arch is 1/4.5 and the axis is a centenary curve. The truss arch rib is 3m high and 2m wide, composed of four CFST chords. The piers of the bridge are also CFST columns. The floor system is steel-composite structure, composed of prestressed steel transverse box beams and precast prestressed concrete hollow slabs (Li Yong, Nie Jianguo, Chen Baochun and Chen Yiyan, 2000).

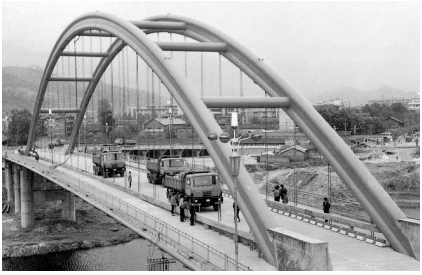


Figure 2: Wangcang Donghe Bridge

Figure 3: Shenzhen Beizhan Bridge

The longest span of such bridge form is 280m in No.3 Hanjiang Bridge (Fig. 4) in Wuhan City. It has a span of 280m, carrying four lanes width of 15m and two side-waling ways, each has a width of 2m. The rise to span ratio of the arch is 1/5. The arch ribs are two 5.5m high CFST trusses. Four chord members in each rib are steel tubes of $\Phi 1000\times12$mm filled with C50 concrete. Total of 9 tube bracings are provided at the two ribs. The bridge is completed in 2000.

Rigid-frame tied through arch bridge generally has a main span. Investigation on this bridge type shows that there are 22 bridges out of the built 30 are bridges with a single-span, only other 8 bridges have two or three spans.

Lanzhou Yanyan Yellow River Bridge (Fig. 5) is a three-span rigid-frame tied through CFST arch bridge, with a span arrangement of 85m+127m+85m. The arch axis in all of the three spans is parabola, and the rise to span ratio is 1/5. The deck of the bridge is 31m wide, carrying 8 lanes. The CFST arch ribs are fixed in the piers and the arch thrust forces are balanced by separate tied bars for each span. The floor system consists of concrete slab supported directly by pre-stressed concrete box beams at a spacing of 5m longitudinally.

Figure 4: No.3 Wuhan Hanjiang Bridge

Figure 5: Lanzhou Yanyan Yellow River Bridge

2 BRIDGE STRUCTURE

As other type CFST arch bridges, parabola and centenary are the common used arch axis. The ratio of rise to span generally is 1/5. In multi-span bridges, the continuous arch effect is weak, in other words each span be calculated and design separately, especially in scheme design.

The tied bar, supported by the cross beams, is anchored at the tops of the piers. When the prestressed force of the tied bar, balancing the thrust force of the arch, is calculated, it is assumed that the compressive rigidity of the bar is infinite and is given a very large value, and its flexural rigidity is infinitesimal and is given a very small value. Because the pre-stressed force of the tie bar is put on the arch springs step by step with the dead load increasing, the force should be calculated according to the construction steps. After all pre-stressed force is put on, the tie bar should be resumed to their real compressive and flexural rigidity to calculate the structure, including the additional tensile force in tie bar caused by anaphase dead load and live load. Therefore, the tie bar not only balances all the thrust from dead load but also a part thrust from live load in order to decrease the bending moment in arch rib, pier and foundation, so it should be extra-tensioned when the bridge is completed. The maintenance of the tie bar is the most critical for the service of the bridges; it is necessary to take checking and replacement into consideration in its design.

The structure of the joint between the arch spring and arch seat on the top of the piers is very complicated, because arch rib, pier and end cross beams are jointed together and tied bars are anchored there. As a consequence of principal tensile stress, the joint is easy to crack, so it is necessary to carry out detail analysis by spatial 3-D FEM.

Most of the piers are reinforced concrete structures. Sometimes pre-stressed concrete structure or composite column is applied in the pier. The boring pile is commonly used in the foundation of this type of bridge.

3 INTERNAL FORCES UNDER DEAD LOAD

Generally speaking, dead load occupies a large part of the total load in long-span arch bridges. Thus, the dead load should be taken into major consideration in design. This paper presents a simplified calculation of rigid-frame tied through CFST arch bridge under dead load. The Displacement Method is used in the analysis, therefore, the internal force of the rib and pier is associated with the deformation of the arch springing. As shown in Fig. 6, the dead load includes the self-weight of arch rib and floor system.

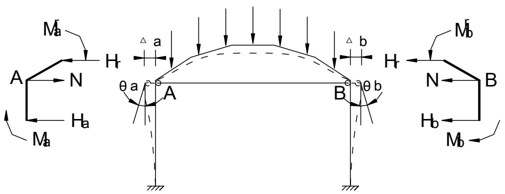
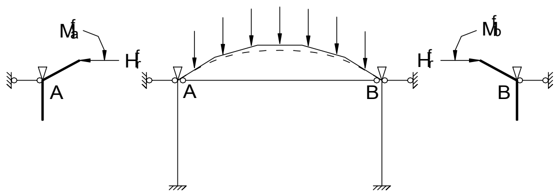
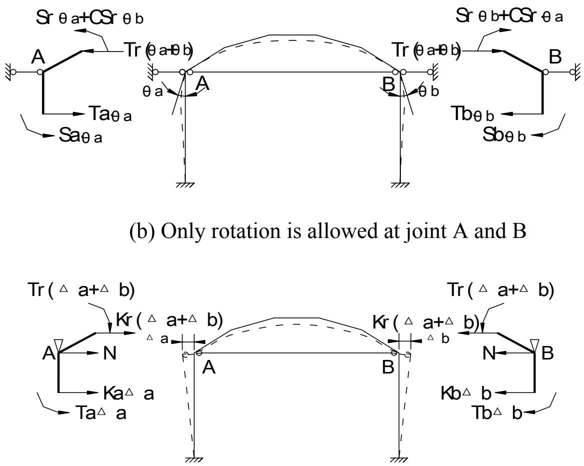


Figure 6: Simplified mechanical system under dead load

Under the load, there will be displacement and rotation at joint A and B. According to the Superposition Principle, the system can be divided into three parts: no deformation is allowed at joint A and B, as shown in Fig. 7 (a), only rotation is allowed at joint A and B (Fig. 7 (b)), and only displacement is allowed at joint A and B (Fig. 7 (c)). The symbols used in the equation can be calculated when the bridge have been determined (Wang Guo-ding, 1998).



(a) No deformation is allowed at joint A and B



(b) Only rotation is allowed at joint A and B

(c) Only displacement is allowed at joint A and B

Figure 7: Separated mechanical system under dead load

According to the equilibrium condition of the thrust and bending moment at joint A and B, the equation of rotation and displacement can be obtained as follow.

$$\theta_a(T_a - T_r) - \theta_b Tr + \Delta a(K_a + K_r) + \Delta b Kr + \frac{EA(\Delta a + \Delta b)}{l} = H_r^f$$

$$-\theta_a Tr + \theta_b(T_b - T_r) + \Delta a Kr + \Delta b(K_b + K_r) + \frac{EA(\Delta a + \Delta b)}{l} = H_r^f$$

$$\theta_a(S_a + S_r) + \theta_b CSr + \Delta a(T_a - T_r) - \Delta b Tr = M_a^f$$

$$\theta_a CSr + \theta_b(S_b + S_r) - \Delta a Tr + \Delta b(T_b - T_r) = M_b^f$$

The rotation and displacement at joint A and B can be obtained from above equation, and the force in the arch and pier can be derived as follow:

$$N = W \times (\Delta a + \Delta b);$$

$$Hr = H_r^f - [Kr(\Delta a + \Delta b) - Tr(\theta_a + \theta_b)];$$

$$M_a^r = M_a^f - \theta_a Sr - \theta_b CSr + Tr(\Delta a + \Delta b);$$

$$M_b^r = M_b^f - \theta_b Sr - \theta_a CSr + Tr(\Delta a + \Delta b);$$

$$M_d^r = M_d^f - \frac{M_a^r - M_a^f + M_b^r - M_b^f}{2} - [Tr(\theta_a + \theta_b) - Kr(\Delta a + \Delta b)] \times f;$$

$$H_a = \theta_a Ta + \Delta a Ka;$$

$$H_b = -\theta_b Tb - \Delta b Kb;$$

$$M_a = \theta_a Sa + \Delta a Ta;$$

$$M_b = -\theta_b Sb - \Delta b Tb.$$

The force in the arch rib and pier under dead load provide reference in scheme design. The size of the rib and pier can be quickly designed by repeated calculation.

4 CONSTRUCTION METHODS

For the large span arch bridge, it is necessary to reduce its self-weight. Regarding to the CFST arch bridge, the thin-walled steel tubular arch itself, with more outstanding stiffness than concrete members or shaped steel members, can be erected with lighter self-weight. The erected steel tubular arch can be filled with concrete without falsework and formwork.

Because of the arch ribs are fixed at the top of piers, so it can be erected similar to true arch using cantilever launching method or swing method. For small span bridge, the piers can stand small thrust forces caused by light self-weight of steel tubular arch rib and for large span bridge, temporary tied bars can be used. It is easy in construction than in tied arch with deck girder stiffened bridge. The difficulty with the latter arises from the fact that the horizontal reactions are not available until the deck is completed.

The tie bar should be tensioned step by step along with the increase of the dead load in the construction to balance the thrust, therefore, the tension sequence and tension forces of the tie bar must be determined in the design. In order to prevent crack appear in reinforced concrete piers during the construction by in-span horizontal forces caused by pre-stressing of tied bars and out-span thrusts from the arches, a construction monitoring based on carefully calculation according to the construction stages are necessary.

5 CONCLUSIONS

The rigid-frame tied through arch bridge is widely used in China nowadays, especially in cities. In this bridge type, the tie bar is the most critical member, which is easy to be damaged because of corrosion. So it is necessary to pay more attention to the design of the tied bars. The simplified method in this paper can be used in the scheme design to calculate the internal force in rigid-frame tied through arch bridge under dead load.

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