Design and construction of Hechang Bridge, Quanzhou, China

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ABSTRACT**:** Hechang Bridge is a pedestrian bridge, located in the campus of Yang-En University, Quanzhou City, Fujian Province, China. A half-through lift-basket CFST arch bridge with a clear span of 100m was selected finally after enough homework on selecting bridge type. This paper will introduce its design and construction.

1 INTRODUCTION

The Hechang Bridge is located in the campus of Yangen University, Quanzhou City, Fujian Province, China. The bridge crosses over the river in the upstream of a reservoir with a width of the water level about 100m to link the old campus to a new sport ground. Because of the river water is rather deep, no piers in the river bed will make the bridge construction easy and economical. Thus a span not small than 100m is considered and choice of bridge types was among a cable stayed bridge, a suspension bridge or an arch bridge. A half-through lift-basket CFST arch bridge was selected finally based on the following three main reasons:

(1) It was less expensive and more suitable for a 100m span.

(2) The arch further the tradition of the existing old arch reinforced arch bridge in the campus over the same river and its beautiful configuration and vivid color can conform with its surroundings and environment.

(3) For a CFST arch bridges, the thin-walled steel tubular arch itself can be erected with light self-weight and then be filled with concrete without falsework and formwork. This improves the construction speed and saves the cost for construction. The design elevation of Hechang Bridge is shown in Fig. 1.

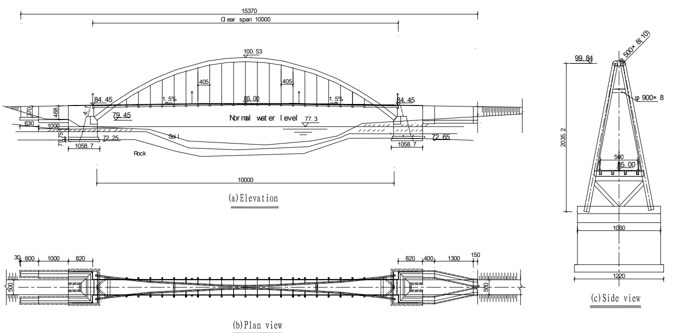


Fig. 1 Elevation of Hechang Bridge (unit: cm)

2 DESIGN FEATURES

The total length of Hechang Bridge is 153.7m with a pedestrian path of 5m wide. The design live load is 4.5 kN/m^2. The ratio of clear rise to clear span of the arch is 1/5. The arch axis is a catenary as shown in Equation (1).

$$y = \frac{f}{m-1}\left(ch\frac{2kx}{l} - 1\right) \quad (1)$$

where : y and x is the vertical and horizontal coordinate of the arch axis resepectively, as shown in Fig. 2 ; m and k is related parameter in centenary curve ($k = \ln(m + \sqrt{m^2 - 1})$) ; f and l is the rise and the span of the arch. For Hechang Bridge, m=1.167, k=0.57, f=2066.7cm and l=10212.4cm, so its axis is as follow

$$y = 12375.4(ch0.000111629x - 1) \quad (2)$$

Because Hechang Bridge has a span of 100m but only 5m wide, so a lift-basket arch was chosen to improve the out-of-plane stability of the structure. Generally the inward inclination of lift-basket arch is between 3°-15°and 10°is mostly used[1]. So the two arch ribs in Hechang Bridge are inclined inwards 10°. The axis of the arch is as follows:

$$y^* = y\cos\varphi; z^* = B_d / 2 + y^* \tan\varphi \quad (3)$$

where : y^* and z^* are the vertical and transverse coordinate of the inclined arch axis resepectively, as shown in Fig. 2 ;

φ—inclined degree (it is 10°in Hechang Bridge) ;

B_d —the distance of two arch rib axes in crown (it is 83.2cm in Hechang Bridge)

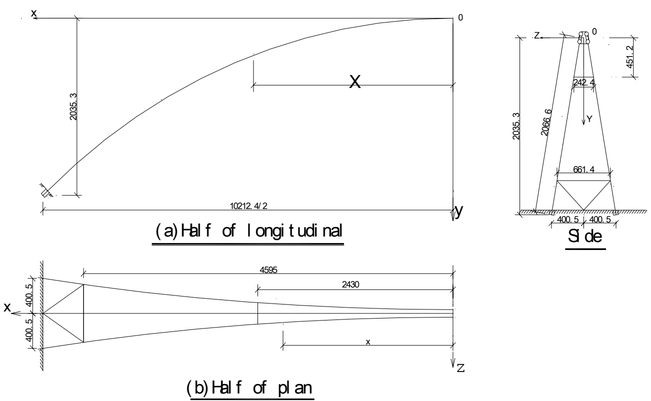


Fig. 2 Axis of Hechang Lift-bascket Arch Bridge (unit: cm)

The arch rib is a pair of CFST dumbbell rib. Each rib is composed of two steel tubes filled with C40 concrete and welded together by two steel web plates. The diameter of the steel tube is 500mm with a thickness of 10mm in spring segments (section I) and 8mm in other segments (section II), as shown in Fig.3. In order to prevent the cracks in the weld sealing between steel tube and web plates when concrete fills into the web space, stiffened steel plate is used to reduce stress, as shown in Fig.4.

,Lateral bracings between the two ribs are used to guarantee the overall and local stability of arch ribs. The type and position of lateral bracings are: (1) one V-shaped bracing between the arch ribs under the deck; (2) three single tubes over the deck. Based on lateral bracings and lift-basket ribs, the transverse connection is enhanced and the structural stability in out-of-plane direction is improved.

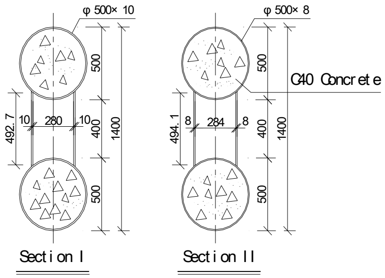


Fig. 3 Cross-section of arch rib (unit: mm)

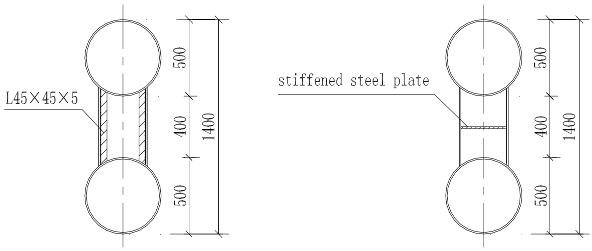


Fig. 4 Stiffened steel plate (unit: mm)

Structural deck system is composed of PC cross beams, main girder and concrete pavement, as shown in Fig.5.

The general cross PC beams suspended by hangers are 6.6m long with a rectangle-section of 0.4m wide and 0.7m high. The bracings connected the two main arch ribs at the deck level are solid beams with 6.6m long, 1.05m wide and 1.05m high.

The cross beams is suspended by hangers. The inclined hangers are circle steel tube and are generally in a single cable. The longitudinal distance of hanger is 4.05m. The diameter of each hanger is 45mm with the strength of R_Y^b=210MPa. Structural diagram of the hanger is shown in Fig.6.

The longitudinal laps between adjacent π -shaped RC deck slabs and transverse laps between slabs and cross beams are cast concrete in-situ to form whole deck plate. The 8cm thick concrete will cast in-situ covering the deck.

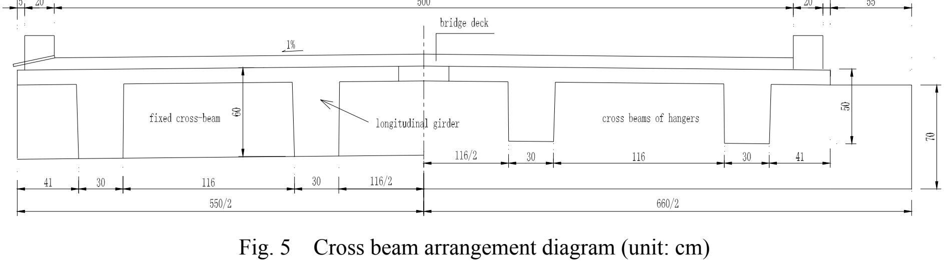


Fig. 5 Cross beam arrangement diagram (unit: cm)

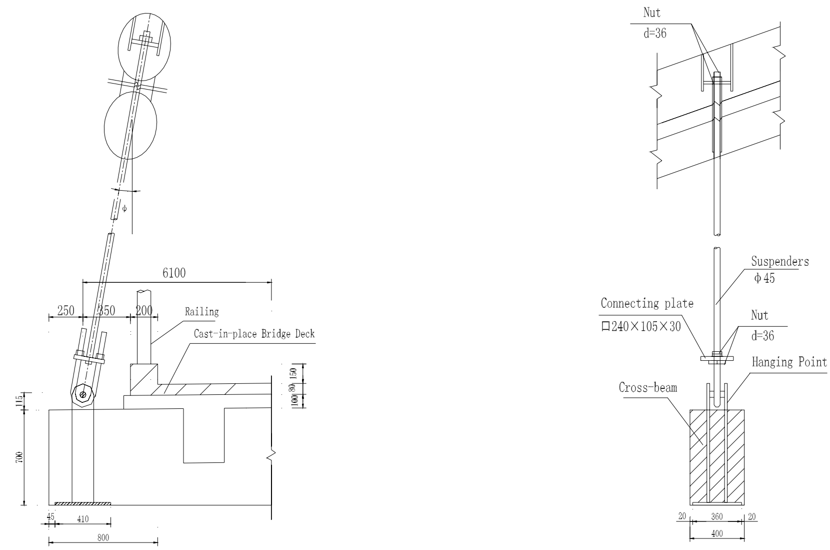


Fig.6 Suspender arrangement diagram (unit: cm)

Two abutments at each side are composed of two parts with shallow foundation. The front part is a concrete U-shaped structure to support mainly the vertical forces and the back part is composed of two long stone walls to resist the horizontal thrust from the arch ribs.

3 CONSTRUCTION TECHNIQUES

As we know, construction of a concrete arch rib is a real challenge for its heavy selfweight. An important advantage of the CFST arch bridge is that the hollow steel tube arch itself can be erected with lighter self-weight than the concrete member and larger stiffness than shaped steel arch. This erected steel tube arch can be filled with concrete without false-work and the system can be converted into composite structure without form-work. Thus, the structure is capable of bearing the service load as designed. The erection methods of the hollow steel tube arch are often the cantilever launching method with cable crane and the swing method.

Each steel tubular arch rib of Hechang Bridge was divided into three segments and fabricated in workshop while the abutments were built on the site. The steel tubular arch ribs were erected by cantilever launching method with cable crane (Fig. 7).

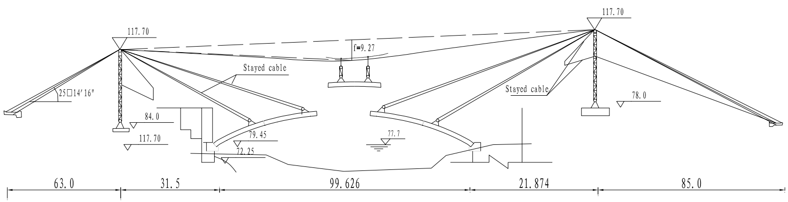


Fig. 7 Erection of arch rib (unit: mm)

The span of the cable crane was 153m with a cable tower height of 39.0m and width of 12.0m (clear width of 9.0m). The main cable is a 2φ47.5 steel wire rope. Each steel tubular arch rib of Hechang Bridge was divided into three segments and fabricated. The largest hoisting weight is 12.3t. The two spring segments of arch rib were stayed by 2φ36.5 wire ropes before the crown segment erected and closure of the arch ribs. In order to guarantee the structures stability during construction, wind cables were used in both the cable towers and the erected steel arch ribs.

Concrete was filled into the steel tubes to form CFST arch ribs after the closure of the arch ribs. Then the precast reinforced cross beams were lifted and positioned and the concrete deck was cast. Construction began in July 2001 and was completed in Feb. 2002 (Fig. 9).

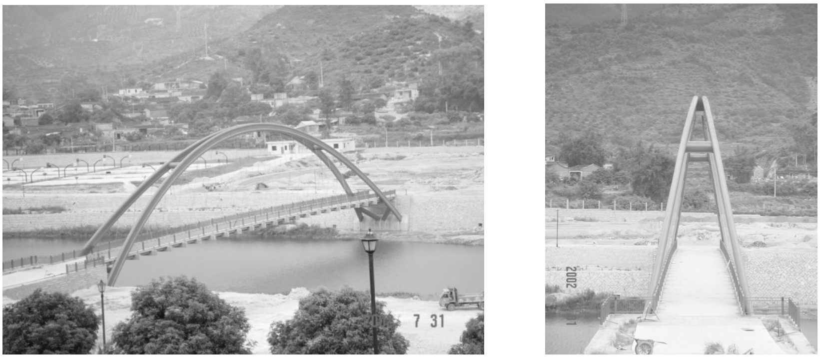


Fig.9 Hechang Bridge

4 FINITE ELEMENT ANALYSIS

A three-dimensional finite element model has been developed to analyze the bridge. Arch rib is simulated by beam elements. The stiffness of CFST section is calculated by the following equation:

$$EA = E_c A_c + E_s A_s \ ; \ EI = E_c I_c + E_s I_s \tag{4}$$

where, E_s, A_s and I_s are the Young modulus, area and inertia of steel section; E_c, A_c and I_c are the modulus, area and inertia of filled-concrete section.

Hangers are simulated with truss elements. The concrete deck slab is also modeled by two-node beam elements. The pavement layers did not have their own geometrical and inertial properties, only masses. The arch ribs are assumed to be fixed at the abutments. As a result, the model has a total of 482 elements, 358 nodes. Fig. 10 shows the full three-dimensional view of the finite element model.

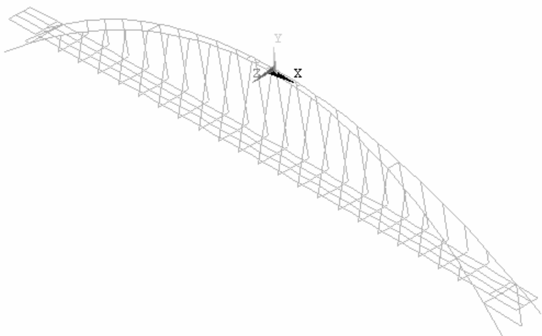
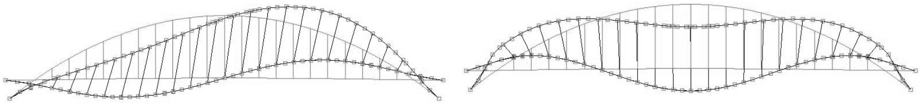


Fig.10 Spatial FEM model

Static analysis was performed under the self-weight and live load according to China Highway Bridge Design Code. Comparing the maximum strength of arch rib obtained from the static analysis shows that CFST arch ribs are expected to be safe during its service life. The largest deflection of the bridge deck is 3.5cm under the service loads, smaller than the allowable deflection (L/800=12.5cm). Therefore, the stiffness of bridge can meet the requirement for design.

Analyzed by the eigenvalue method, the elastic buckling shape of the structure subjected to dead loads and dead loads plus live loads was out-of-plane instability, as shown in Fig. 11. The safe factor of elastic buckling load compared to dead load is 9.298, which is large than the standard value of 4.

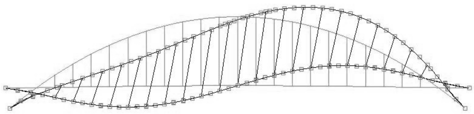
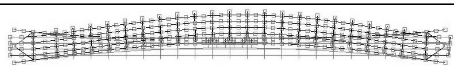
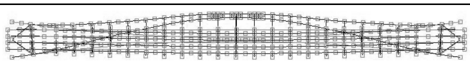
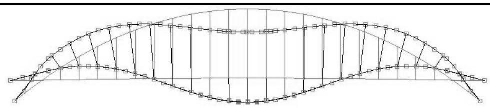


(a) 1st (b) 2nd

Fig. 11 Elastic buckling shapes

Dynamic analysis was performed on the three-dimensional model using finite-element techniques in order to obtain the eigenvalues and eigenvectors of the structure. The model included masses and stiffness as in the real structure. Masses were distributed on beam elements. Results are given in Table 1. The first in-plane natural vibration has a frequency of 0.740 Hz, which corresponds to the unique antisymmetric mode of arch bridges.

Table 1 First nine natural frequencies of the bridge

No.	Modal shape	Frequency (Hz)
1		0.740
2		0.893
3		1.105
4		1.371

5 CONCLUSIONS

A CFST lift-basket arch bridge has been designed and constructed in Quanzhou City, Fujian Province, China, as a pedestrian bridge to connect the two part of the campus of Yang-En University and has been a landscape of the campus. Two arch ribs inclined inwards not only strengthen the out-of-plan stability of the arch structure, but also give a good aesthetic appearance. Therefore, we can say that the lift-basket arch results from a harmony meeting of art and science in Hechang Bridge.

REFERENCE

[1] Baochun Chen, 1999.*Design and Construction of CFST Arch Bridge*. Beijing :China Communications Press, China.