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DESIGN AND CONSTRUCTION OF NAPU BRIDGE, ZHE-JIAN, CHINA

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Abstract. *Napu Bridge, located in Chunan, Zhe-jian Province, is a half-through concrete filled steel tubular (CFST) arch bridge with a clear span of 308.00m. It is one of the largest CFST arch bridge under construction in China. The major issues in design, the erection of steel tubular arch and the construction of concrete filled steel tubes are presented in this paper.*

1 INTRODUCTION

Napu Bridge, located in Chunan, Zhe-jian Province, crosses the Qiandao Hu (Thousand Islets Lake) in its narrow part in the upstream side. Qiandao Hu is an artificial lake formed as the result of constructing a reservoir for Xin’an River Waterpower Plant in 1959. It is one of the first-class national scenic spots and is the largest national forest park. It has a storage capacity of 17.8 billion cubic meters, covering an area of 143, 321 acres. It has a total of 1,078 islets, each with its own formation. That is why the lake is named Qian Dao Hu (Thousand Islets Lake). The average depth of water is 34 meters (112 feet) and the visibility in the water can be reached to 7-9 meters (23-30 feet).

Napu Bridge is located in local road to connect the two side of the lake. The width of the water level, where the bridge will over pass is about 300m. Considering the economy and speed of construction, no pier was permissible in the water, because it is very deep. Because of the terrain of deep gorges with steep rocky banks and large body to across, an arch is a suitable structure to be selected. Moreover, an arch form is aesthetically the most pleasing and can be a new landmark at the famour scenic spots.

Considering the difficulty to erect the reinforced concrete arch and expensive cost of steel arch, concrete filled steel tubular (CFST) arch bridge was proposed. CFST arch bridges have been developed quickly in China since 1990 and about 200 such bridges have been built or under construction, among them the largest one is the Yijisha Bridge with a main span of 360m[i]. In order to prevent the under water construction, the foundations of the two abumtments are at the land, thus a clear span of 307.94m is decided. Napu Bridge is a half-through CFST arch bridge with a rise to span ratio of 1/5.5. It is the second CFST arch bridge with a span larger than 300m that has completed in China. The design and construction will be introduced in this paper.

2 SUPERSTRUCTURE

The design criteria for the Napu Bridge were generally based on Chinese national standards. The design live load consists of the Super-20 vehicle loading, the Grade 120 trailer loading and pedstrain loading of 3.5kN/m2. Earthquake reaction is considered based on the Chinese Seismic Standard with intensity of seventh grade. Its width is only 12m, in which 9.0m for traffic lane and 2×1.5m for walk side road. The distance outside to outside of the two CFST ribs are only 13.85m, but the clear span of the arch is larger as 307.94m that leads the ratio of width to span is 1/22.2, which is very small for an arch bridge. The elevation of the bridge is shown in Fig. 1.

The bridge has two parallel arch ribs. The rib axis is a catenary curve with a parameter m of 1.167. Four chord members in the arch ribs are steel tubes Φ850mm diameter filled with C50 concrete, the thickness of the steel tube generally is 12mm except 14mm in the hanger anchor place and 20mm in the arch spring. The vertical and the diagonal web members are made up of steel tubes Φ529×10mm. The lateral bracing members of the CFST chords are also hollow steel tubes, Φ529×10mm for the general members and Φ600×14mm for hanger anchor tubes. The general cross-section of the arch rib is shown in Fig. 2.

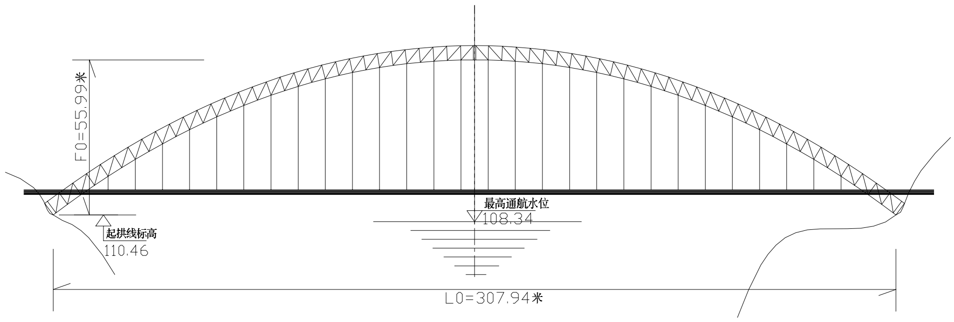

Fig. 1 Elevation of the main bridge

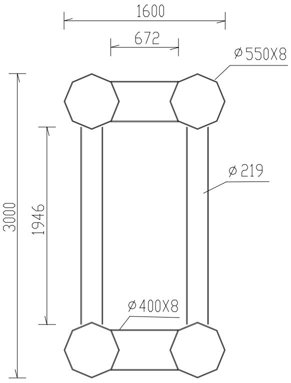

Fig. 2 General cross-section of the arch rib（Unit：mm）

The two parallel arch ribs with a central distance of 13.0m are connected by 13 bracings. The bracings are K-shaped steel tubular trusses except the one at the crown in a double K shaped.

The deck are supported on the cross beams which is suspended by hangers set apart at a distance of 10m. The hangers are cables with PES（C）7-055 threaded high-strength steel rods. The strand anchorage is the PESM7－055 type of cold cast steel socket.

The floor system is composed of PC cross beams and continuous RC narrow T-shaped beams. There are 28 PC cross beams with C50 concrete in the bridge. The RC deck beam (slab) are precast and connected in longitudinal and cross direction by concrete cast-in-situ. The deck pavement is 10cm thick steel-fibre concrete. At the abutments, deck beams are supported by PTFE slide plate rubber bearing and concected to the abutment by SSFB－D160 type expansion device.

The two separate abutments at each side are connected together by RC cross beams and cap beams. The abutments are laid directly on the rock foundation. All the abutments as well as their foundations were built of cast in situ reinforced concrete. Because they are located on land, their construction was not difficult and the excavacions were done by excavator and hand digging.

3 FABRICATION OF STEELWORK

Steelwork procurement and fabrication were recognized as the most critical items affecting the overall construction schedule. Substructure and foundation construction work was relatively straightforward. According to the difficult traffic condition, the bridge steelwork was assembled near the right-hand abutment with a yard of 26×125m where a gantry crane of 40t was employed. The main steelwork included 24 segments of arch ribs (one rib for 12 segment to hoist) and 13 bracing truss members. All of these segments were welded members with a maximum weight of 58t, out to out size of 32m×6.05m×3.4m .

The steel tube employed in these segments were rolled from plates and welded to form a tube with spiral seams by the embedded arc auto welding method in the steel tube plant. The steel tubes were trucked to the site and welded into segments in the in-situ plant. Arch rib curve is composed of spliced straight steel tubes.

The steel members were blast cleaned and treated with a protection/coating cycle. The outer skin of steel tube is protected by aluminum-coating system painted by electric arc thermal spraying method.

4 ERECTION

The steel tubular arch ribs were erected by cable crane method. The suspension cables of the crane with a main span of 338.5m, passing over saddles on two temporary towers erected behind the abutments and anchored in the rock. The towers with a wide of 18m in the bottom and 22m in the top were made by steel members. The lifting capacity is 65t.

The segments were barged from the assembling yard by the gantry to the site and picked up by the cable crane and set into their final position one after the completion of the other. The erection of segments was done in a symmetrical manner starting from each arch abutment. There was a temporary hinge at the spring of the first segment connected to each abutment in order to adjust the axis of the erected parts of the arch ribs easily. Each segment was lifted into position by the crane cable, temporarily connected to the adjacent segment by the inner flange, and held by tie backs within the plane of the arch rib. Level and trasverse adjacent of the arch axis was achieved by stressing jacks at the anchored ends of the tiebacks and the additional temporary horizontal cables, respectively. The corresponding bracing trusses were erected after the erected segments of the arch ribs welded to the adjacent segments. Fig. 4 shows the erection of the last segment before closure.

Fig. 3 Steel segment fabricated in site

Fig.4 Erection of Steel Arch Rib

After the closure of steel tubular arch, filling concrete into the tubes will be the key issur in the construction. In Napu Bridge, a total of about 1280 cubic meters of concrete with agrade of C50 was filled into the steel tubes by concrete pumps one tube by the other. The concrete should have a good working property to be pumped from the spring section to the crown with a rise of 56m and through smoothly many inner flanges in connections of the lifting segments. Many concrete mixes were tested and compared. The selected composition of concrete mix is shown in Table 1. Chinese ordinary Portland cement with a no. 42.5 was used as binder, natural samd with a fineness modulus of 2.6～3.0 as fine aggregate, and crushed limestone with a maximum norminal size of 20mm as coarse aggregate. Fly ash used in mix no.1 were the finely ground ones. A nagpthalene super-plasticezer was used to get a workable concrete. Expansion agent of UEA was employed to produce expansion to compensate the shink of concrete.

Water	Fly axh	Cement	Expansion agent	sand	Limstone	super-plasticezer
190	60	465	70	570	1040	7.10
185	60	465	70	570	1050	7.10

Table 1 Composition of Concrete Mix（kg/m^3）

The concrete was filled into tubes one after other. Two separate crews at two abutment sides for a tube started at the spring section at the same time and worked up to the crown. There was a diaphragm in the tube near the crown section to restrict the overflowing of concrete from one crew side to the other and a symmetrically sequence was required to prevent overstressing of the ribs. The concrete filling work of a tube should not start before the concrete filled in the last one reaching 80% of its design strength.

When all of the concrete inside the steel tubes were cured and reached its design strength, installation of the cross beams were started, followed by the RC π-shaped slabs placeings.

5 CONSTRUCTION CONTROL AND LOADING TEST

The Napu Bridge is the second CFST arch bridge with a span larger than 300m that has completed in China. In order to ensure a smooth construction process, various checkings were carried out at all stages of construction. Dimsensional control was carried out during fabrication on the plate thickness and on the geometry of shop- and field-assembled parts. During erection, the profiles and alignments of the arch ribs as well as the stresses in some cross-section of the ribs were checked by the pre-analyses results andjusted by the actual factors in the erection process.

A full-scale loading test was also carried out to satisfy state requirements for such bridges. Ten trucks, each 300kN, were used for static testing in four postions: in order to check maximum forces in chords at spring section, at quarter section and at crwon section as well as maximum bending mement at the cross beam. Deflections of the deck and the arch rib at each octant point of the span, stresses of the steel tube at spring, quarter point and crwon sections as well as the stresses of 8 points in the mid-span of No.2 cross beam were measured. The forces of the hanger cables subjected to dead loads were measured by ambient vibration testing method.

For the dynamic tests of the whole structure, a single 400-kN truck was used, crossing the bridge at different speeds of 10km/h, 20 km/h, 30 km/h, 40 km/h and 60 km/h and driving over a bump 7cm high and 40cm wide. Further measurements were made with the same truck braking at the center of the baridge. In addition, the bridge frequency and model was carried out conducting ambient vibration testing under traffic-induced excitation.

The bridge was completed and opened to traffic in August 2003 (Fig. 5).

Fig. 5 Napu Bridge