A key technique of construction for Wuxia Yangtze River Bridge

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ABSTRACT**:** Wuxia Yangtze River Bridge is the largest CFST arch bridge in the world with a clear span 460m. Steel tubes of the arch ribs are prefabricated in firm by segments, and a composite coating of arc spraying with allumen is adopted to prevent tube surface from corrosion before shopping. Rib segments are shipped to the position via the Three Gorges dam, a cableway system is used to hoist and shift rib segments to its position. To ensure the stability of rib segments before the closure, a special designed strand anchorage system is used to stay rib segments to a temporary steel tower as a temporary support. A flange structure is taken as the temporary joint of rib segments. The joint of adjacent segments is welded on site after the completion of the linetype adjustment of arch ribs. Eight rib chord tubes are filled with C60 concrete and the pouring of each tube is finished one time. To ensure the quality of concrete, a new optical fiber sensing technique is applied to monitor the distribution of crack in the filled concrete.

1 INTODUCTION

Wuxia Yangtze River Bridge that crosses the Yangtze River is located in the famous Three Gorges scenic spot. Main bridge is a half-through arch bridge with main span 492m(clear span 460m) and its ratio of sag to span is 1:3.8, south approach bridge is 6×12m prestressed continous beam bridge and south approach bridge is 3×12m prestressed continous beam bridge(with same style). The bridge with total length of 612.2m, has exceeded the Yajisha bridge of Guangzhou that was built in 2000 with a main span 360m. It is the longest bridge in the world heretofore.(see figure 1)

1.1 Main arch ring

The rib of bridge consist of CFST tube trusses , the height of top section of main span rib is 7.0m and the root section is 14.0m, the width of rib is 4.14m, arch axis coefficient is 1.55, clear ratio of sag to span is 1/3.8.

The section of main arch ring is comprised of two ribs and each rib is composed of 4 tubes-two Φ1220×22mm and two Φ1220×22mm chord filled with C60 concrete. Chord is connected by horizontal Φ711×16mm and verticalΦ610×12mm truss tubes. The chord near to suspender is strengthened with diagonal truss tubes between 2 web tubes for enhancing lateral connection. The distance between arch ribs is 19.7m, Arch rib truss is divided to 11 segments along the axis half span, and whole bridge has 22 segments that is divided to upper and lower reach rib across the axis, the two ribs are connected with K type truss lateral bracing above the deck and X type truss lateral bracing under the deck. A plate lateral bracing is designed to connect the deck and arch ribs. There are 20 lateral bracings of the bridge. The joints of arch ring have two types: main chord tube joint and the closure joint structure. The joints are designed to bolt temporarily before welding.

1.2 Suspender

Suspender is made of 109φ7mm galvanized prestressed steel wire and OVMLZMT - 109 chill casting anchorage with nut for adjusting height of the beam in end. A polyethylene sheath is adopted to protect the suspender wire.

1.3 Cross girder and deck slab

Suspender girder and pier girder are both prestressed concrete compound section beam. The girder between arch ribs is made of steel plate for conveniently installing and connecting, a longitudinal support between rib girder and end suspender girder is assembled to limit the longitudinal deflection.

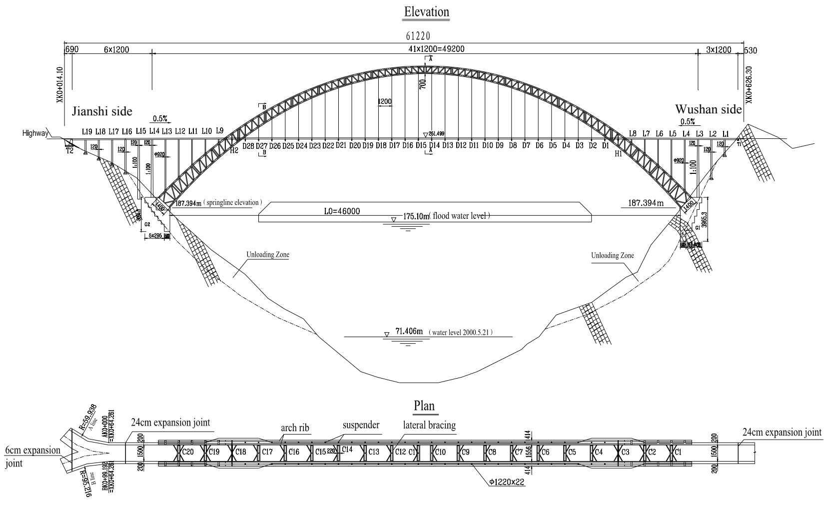

Figure 1:General plan of Wuxia Yangtze River bridge

Vehicle girder is prestressed concrete continous beam withΠ-type section of height 110cm. The clear width of deck is 19.0m.

The construction of bridge includes arch ribs prefabrication and corrosion protection, arch support construction, arch ribs installation, pouring of concrete, suspender installation, girder and deck slab construction.

2 PREFABRICATION OF ARCH RIB

Bridge arch ribs are prefabricated by Wu chang shipyard Co. Ltd and Chuan dong shipyard. According to the feature of arch rib, arch ribs are fabricated with arch rib segments and lateral bracing separately. Arch rib segments prefabrication includes tube coiling, lofting, laying off and cutting, rectification, assembling and welding.

Longitudinal and circumferential joint of arch rib tube are welded by automatic arc-submerging welder, fully Penetrating weld. The joints on site are welded by semi-automatic carbon dioxide gas shielded arc welding.

The joints are inspected by ultrasonic and ray flaw detection. The quality of joints should fulfill the ultrasonic flaw detection I class of TB10212-98 and ray flaw detection B class of TB10212-98. joint

3 ARCH RIB TUBE CORROSION PROTECTION

The tubes of Wuxia Yangtze River bridge arch ribs are prevented from corrosion by composite coating of arc spraying with allumen of over 30 years' estimate life. The detailed scheme is:

Metallic surface treatment class: Sa3;
Arc spraying with allumen 160μm (zinc 85% , aluminium 15%)
Micaceous iron oxide epoxy intermediate coating 2 layers(50μm)
Acrylic acid Polyurethane final coating 2 layers(50μm).

4 INSTALLATION OF ARCH RIBS

4.1 General scheme

A cableway system with stay cable is used for the installation of arch rib segments. A symmetrical cantilever erection method is adopted to the construction of arch ribs. Half span is divided to 11 segments(22 hoisting segments) and 6 segments of cable stay.

The first segment of cable stay has 3 segments of hosting, the 2nd segment of cable stay has 2 segments of hosting, so do 3rd and fourth segment of cable stay. The others, each segment corresponds to one segment of hosting respectively.

Single rib segment is hoisted one time, a lateral bracing is assembled to form a double rib segment after the accomplishment of single rib segment of lower reach or upper reach.

A rib segment is hoisted one time, there are 64 hoisting segments in total, the heaviest segment has 118 tons (170 tons for lifting) and lateral bracing has 40 tons to lift.

One cableway system is only utilized for hoisting one arch rib because of the distance of 2 arch ribs. One hoisting segment is lifted by 4 hoisting device simultaneously, the lateral bracing is lifted by 2 hoisting device near the bridge axis for its weight and position.

After the prefabricated rib segments are preassembled, they are shipped by special barge to their anchor position via the three Gorge dam. From 1# segment near the arch support to the 11# segment, segment is hoisted and shifted to its position separately. After the adjustment of bridge axis and the control of elevation, a bridge closure is fulfilled with joining a key segment between two 11 segments.

Each joint is welded to form arch without articulation. After symmetrically releasing cable stay step by step, the installation of arch ribs is finished.

4.2 Cableway system

4.2.1 General scheme

Cableway system consist of cableway, arch rib cable stay system and arch rib stabilization system.(see figure 2, there is no temporary cable stay of Wushan side, equilibrium rope of cable stay tower, arch rib wind cable shown in figure 2)

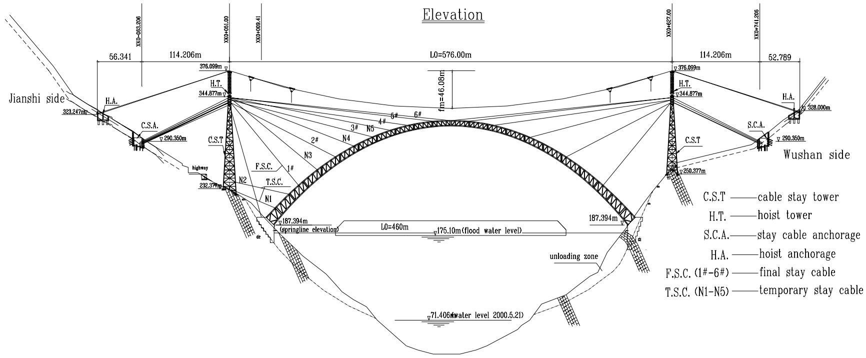

Figure 2: General plan of Hoisting-cable stay system of Wuxia Yangtze river bridge

The cableway for hoisting is comprised of main cable, hoist tower, longitudinal win cable, hoist anchorage, power machinery of hauling and hoisting.

Cable stay system of arch rib is composed of anchorage end of arch rib, strand stay cable, cable stay tower, equilibrium rope of cable stay tower, anchorage of stay cable (including tension end of stay cable).

Arch rib stabilization system consist of anchorage end of arch rib, wind rope and anchorage.

4.2.2 The characteristic and difficulty of cableway system

The layout of cableway is difficult because of narrow construction field and precipitous terrain. The construction of arch rib truss has the characteristic:

The span of cableway has long span(576m), heavy lifting weight(up to 170 tons), super lifting height(260m).

Bridge is located at the gateway of Wuxia with gust over 7 class of Beaufort scale.

A series of key technique are developed to fulfill the construction of bridge.

4.2.3 Cableway

Hoist and cable-stay tower

Cable-stay tower is separately located outside the main arch support, has a height of 94.5m （Wushan side）and 119.5m（Jianshi side）, the distance of two tower is 576m. Each tower is composed of 8Φ610×10mm steel tube filled with C60 concrete, tube bracings are used to connect pillar structure to form a whole welded lattice column structure.

Hoist tower stands on the cable stay tower and a hinge is used for connecting the two towers to reduce the effect that the former exerts on the latter furthest.

Hoist tower assembles with M-type universal rods, height 31.2m, a bracing beam is designed at the half height of the tower.

In order to make the loads on the 3 rows of vertical member uniform approximately, a rubber bearing is adopted for the middle fulcrum of distribution beam on the top of the tower.

Because of the limitation of terrain, only longitudinal wind cable is designed to ensure the stability of the tower. The full length wind cable is comprised of 4Φ47.5mm rope, the rope is anchored to the hoist anchorage and fastened to the tower.

Main rope

Hositing system has a 576m main span, 167m (Wushan side) and 171m (Jianshi side) side span. The main rope of anchorage end has a 19.2◦ separation angle with horizon.

A pair of main cable system are designed to hoist arch rib. Each one comprised of 2 group of 4Φ56 wire rope is to undertake single arch rib's lifting.

In order to achieve the identical cable force, every 4 main ropes is connected to one rope with special cable clamp.

A special designed lateral distribution structure is used to ensure the uniform load of each lifting joint when 2 group of cable system hoist the arch rib.

Hoist anchorage

Hoist anchorage uses composite construction of anchor piles and rock anchors that is built independently. There is 4 hoisting anchorage in total.

Rock anchor choose $R^b{}_y$=1860Mpa class strand control stress for prestressing is 0.6$R^b{}_y$. It is anchored to the bearing platform.

Stay cable anchorage has the similar structure to hoist anchorage instead of 6Φ2.5m pillar and front wall with vertical and horizontal prestressed strand. .

4.2.4 Cable stay system

The cable stay system for arch ribs' installation is divided to 5 parts: fixed end, saddle, tension end, strand, cable stay tower.

cable stay tower

As mentioned above. Front and back equilibrium rope are designed to keep deflection along the bridge axis not excess of stated 75mm.

Arc saddle on top of the cable stay is made of rollers that aim to enlarge the bend radius to reduce the bend stress of cable stay strand.

stay cable

Final and temporary stay cable are both fastened to 2 upper chord of ribs, pass the saddle on the tower and enter the tension end of anchorage.

Temporary stay cable is 2Φ47.5mm (Φ47.5mm)steel rope, final stay cable is 4×6Φ15.24～4×9Φ15.24 steel strand, It is typical low stress stay cable anchorage system with safe factor no less than 2.5.

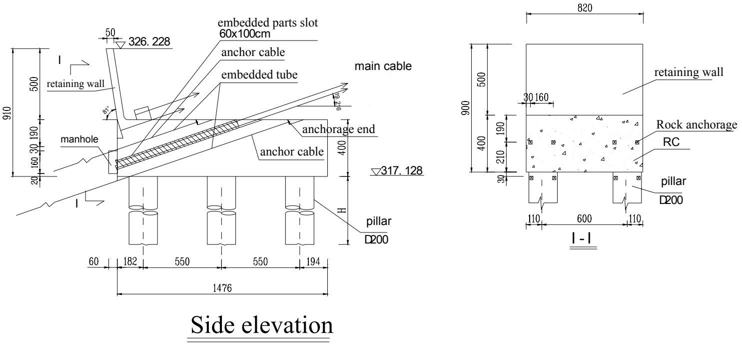

Figure 3: Layout of hoisting anchorage

The stay cable near stay cable anchorage has an inclination of 23.9°～25.3° with horizon. With the progress of construction, temporary stay cable of prior segment is loosen after the tensioning of final stay cable.

fixed-end of stay cable

It is anchored to the tension beam of main chord tube with P type anchorage.

tension end of stay cable

The tension end is anchored to RC wall of stay cable anchorage by low stress clip anchorage. This type anchorage is designed to group tension, anchor with pressing, lock clip with pressing plate.

Low stress anchorage system is composed of embedded steel plate, lock nut, pressing plate , supporting bar, restrict plate, tool anchorage, anchorage etc.

Stay Cable anchorage system adopt YM anchorage to ensure the clip's capability of follow-up under low stress ($0.08R^b_y$-$0.42R^b_y$) , pressing jack presses the clips with the designed 3~6 tons pressure to ensure the safety of anchorage after the accomplishment of tension and self anchor.

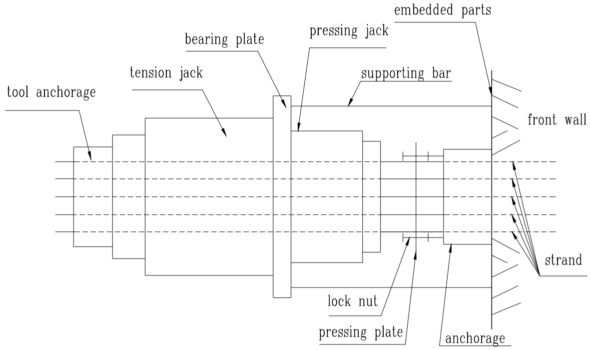

Figure 4: Layout of tension end of low stress anchorage system

Considering the long term vibration due to wind load, pressing plate and lock nut are used to lock the clip and prevent the anchorage from loosing.

4.2.5 Arch rib stabilization system

The joints between arch ribs adopt the high strength bolt structure: a flange designed at the end of truss chord tubes, there is column hinge at the abutment fit for adjusting arch axis and the hinge was fixed after the erection of the 9th arch rib segment.

During the construction of arch ribs, lateral wind cable of the 5th segment and longitudinal wind cable of each segment are designed for fine adjusting method of arch rib lintype.

Figure 5: The view of arch rib tube truss closure of Wuxia Yangtze river bridge

5 THE POURING OF CONCRETE FILLED IN TUBE

5.1 General layout

The Φ1220×22(25)mm main tube, Φ610×22mm vertical web member near the rib to the deck, theΦ1220×22mm upper pillar lateral bracing, theΦ711×16mm suspender lateral bracing are all needed to be filled with C60 concrete. The pouring quantity of each main tube is about 600m^3 .

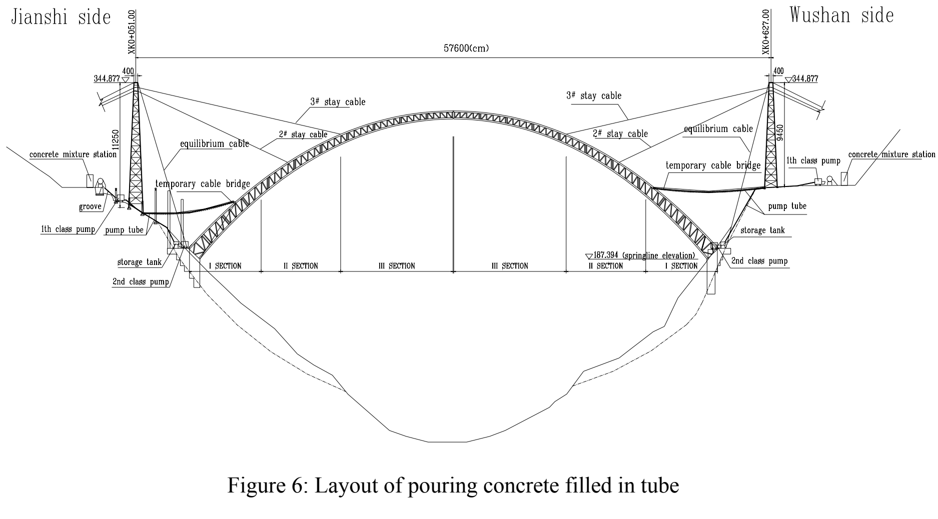

Figure 6: Layout of pouring concrete filled in tube

The pouring of tube concrete carry out according to the principle of symmetry and equilibrium, that is: symmetry loading and taking the arch crown as symmetry line, alternately loading and taking the bridge axis as symmetry line. First to pour concrete into the arch rib tube in sequence, then the vertical web tubes and lateral bracings.

5.2 Specification of inner concrete of tubes

High strength micro-expansion C60 is required. High fluidity, shrinkage compensation, carry -forward initial setting, high early strength are also required. Considering the characteristic of construction and the capability of on site stirring, a slump of 22~24 cm, 4 hours' loss of slump < 4cm, spreading ≥ 40cm, initial setting time 20h (room temperature 20℃), sand ratio 37%~40%, preparing compressive strength no less than 69MPa are required

Expansion ratio is greater than 0.3‰ (14d limited expansion ratio is 0.32‰) according to the design paper.

5.3 Pouring of concrete

The arch rib is divided to three parts from abutment to arch crown and concrete is poured continuously by relay pumping. After one tube is poured and the concrete achieve the 80% design compressive strength, another tube could be poured immediately.

5.4 Inspection of concrete filled in the tubes

5.3.1 The pouring quality of concrete is the key of CFST bridge construction. General method of concrete of CFST bridge inspection include testing by ultrasonic waves and tapping method.

Testing by ultrasonic waves has the following problems: i. estimating depend on experience; ii. Invalid to radial crack; iii no good at joint ; iv. limited by the duration of operation.

Tapping method has the following problems: i. hard to carry out; ii. spot check with a few sample; iii. harmful to structure.

On the basis of other projects, a distributed optical fiber void and crack monitoring technique is brought forward (bring out) and developed. Its theory is based on microbending effect of Rayleigh scattering theory (put forward)

Optical time domain reflectometer(OTDR) is utilized to receive and analyze the backward Rayleigh scattering light, obtain its damped waveform and confirm the value, position and range of void and crack.

The Survival ratio of sensors is 75.3%, this result achieves the anticipation on the whole.

5.3.2 Void-crack inspection of tube concrete

Optical fiber inspection results have been gathered and the occurrence, development and distribution of void and crack are described respectively.

For the sake of contrast, figures detected by general method and Optical fiber inspection are plotted at the same diagram(see figure 7~8), the void of tube arch crown detected by Tapping method is 1.7mm for 6# tube and 2.2mm for the 8# tube separately.

No crack is detected by the sensor.

Upper and lower limit of ultrasonic void evaluation and the connecting line of the middle value of the 2 limit are plotted in Figure 7~8.

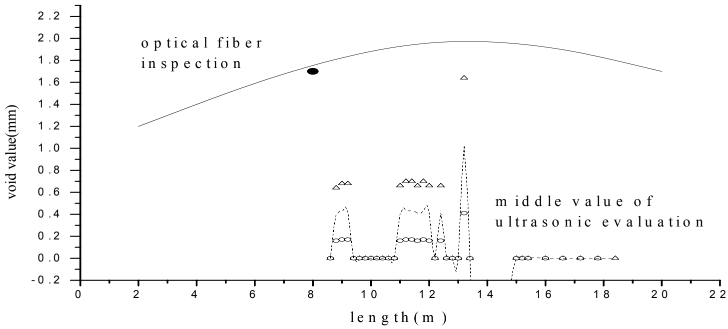

Figure 7: Arch crown void distribution of 6# tube
□ - upper limit of ultra sonic void evaluation; ○ - lower limit of ultrasonic void evaluation
● - tapping method; Vertical axis—void value(mm);horizon axis—length(m)

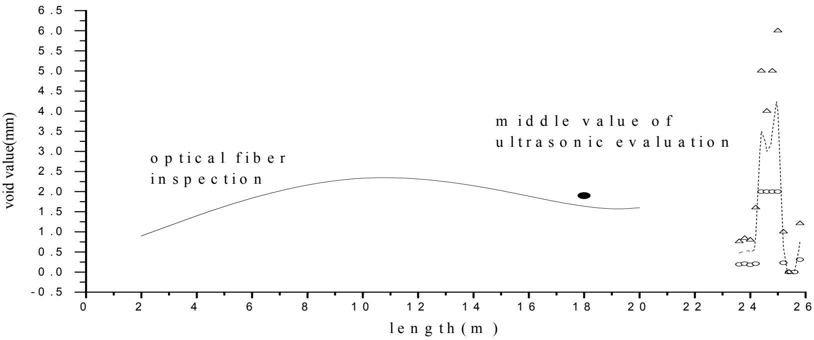

Figure 8: Arch crown void distribution of 8# tube
□ - upper limit of ultrasonic void evaluation; ○ - lower limit of ultrasonic void evaluation
● - tapping method; Vertical axis—void value(mm);horizon axis—length(m)

It is obviously that results detected by optical fiber monitoring match that of ultrasonic method. The void of optical fiber monitoring is consistent with the real value of tapping method.

It concludes that concrete filled in the tube has few tiny void after the inspection. The result fulfill the specification. It proves the reliability of optical fiber monitoring.

But the survival ratio and the service lift of sensors is the problem to be solved next.

6 CONCLUSION

Wuxia Yangtze River bridge construction started on December 28, 2001. Through the application of key technique mentioned above and effort of constructors, the bridge was accomplished and open to traffic on January 8, 2005.

REFERENCES

Baochun, Chen. Design and construction of concrete filled steel tubular arch bridge. Beijing: China Communication Press,2000

Chase, S.B.& Aktan, A.E., Editors, Health Monitoring and Civil Infrastructure Systems, Proc. of SPIE Vol.4337,2001

Feng, M.Q. et al., Instrumentation of bridges for long-term performance monitoring, SPIE, Vol.4337, 2001

Wei, Lu.et al. , The structure analysis of cableway for Wuxia Yangtze River bridge. Proc. Conf. on bridge science and technique of Bridge and Structural Engineering Society CHTS. Chengdu.2003

Zuo-an, Zhang.et al., The development of low stress strand anchorage system for stay cable of Wuxia Yangtze river bridge.Conf. on bridge science and technique of Bridge and Structural Engineering Society CHTS. Chengdu.2003

Zuo-an, Zhang. The key technique of arch rib truss construction for Wuxia Yangtze River bridge. Proc. Conf. on bridge science and technique of Bridge and Structural Engineering Society CHTS. Chengdu.2003

Zuo-an, Zhang. The pouring of concrete filled in the arch rib tubes of Wuxia Yangtze river bridge. Proc. Conf. on bridge science and technique of Bridge and Structural Engineering Society CHTS. Chongqing. 2004

Hu, H. T. et al., Nonlinear analysis of axially loaded concrete-filled tube columns with confinement effect, J. Struct. Eng., ASCE, 129 (10), 2003

Hao-wu, Liu , Optical fiber sensing network for crack inspection of concrete gravity dam , Journal of Hydraulic Engineering , vol.10,1999

Haowu, Liu, Yang Zhaohui. Distributed optical fiber sensing of cracks in concrete. SPIE. 1998, 3555.