

# Key construction technology of Hangzhou Qiantang River 4th Bridge Project of China

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**ABSTRACT:** Qiantangjiang 4th Bridge is located in Hangzhou City of Zhejiang Province, which is famous as a tourist attraction of China. The structure of this bridge is new and unique, and the superstructure of the main bridge is steel pipe concrete arch-beam system arch bridge combined with 11 sizes of spans, the span combination is  $2\times 85\text{m}+190\text{m}+5\times 85\text{m}+190\text{m}+2\times 85\text{m}$ , double deck. The 85m-span structure is combined with through and deck arch bridge, the 190m-span structure is combined with through and half-through arch bridge, and C50 micro-expansion concrete is poured into all the rib steel pipes. The substructure of this bridge is bored pile and pile footing, among them, the pile diameter of the bored pile is 2m, with length of 50m ~ 100m. There are three significant techniques are important to the success or failure of this project, they are as the following: A. this bridge across a world-famous river with strong tide, of which the momentary tidal pressure reaches 70kpa, the construction of the underwater bored pile of the substructure and foundation takes great risk and difficulty. Steel trestle and bored platform were built above the water for the construction of cast-in-place pile, and steel cofferdam and steel sheath box were supplied for bearing platform construction in the water; B. In order to simplify the construction technics, and to avoid the effect for channel caused by the strong tide, the components of the main bridge include: steel pipe arch rib, transverse joining, tie beam, vertical tie of the deck, and transverse beam all adopted unsupported cable for installation. Therefore, one set of double cable unsupported cable hoisting and installing system with span of  $250\text{m}+690\text{m}+650\text{m}+250\text{m}$  and hoisting weight of 130T. C. The diameter of the rib steel pipe of the bridge is 170cm, the cubage of 1 liner meter of concrete in the pipe is  $2.27\text{m}^3$ , and the filling concrete in the rib steel pipe will be continuously jacked up to the top with high pressure concrete pump, which is the most effective method to ensure the concrete quality and to simplify the construction technics. The successful implementation of these three above-mentioned key techniques guaranteed the smooth completion of Qiantangjiang 4th bridge project, and it's also innovation and advance of bridge construction techniques. This paper is to introduce and summarize these three key construction techniques.

## 1. BRIEF INTRODUCTION OF THIS PROJECT

### *1.1 Location and overall layout of this bridge*

Qiantangjiang 4th Bridge is located in Hangzhou City of Zhejiang Province, which is famous as a tourist attraction of China, which is the most convenient access to connect the center of Hangzhou City and Binjiang River (one of the new districts in south area of the Yangtze River). The structure of this bridge is new and unique, and the superstructure of the main bridge is steel pipe concrete arch-beam system arch bridge combined with 11 sizes of spans, the span combination is  $2\times 85\text{m}+190\text{m}+5\times 85\text{m}+190\text{m}+2\times 85\text{m}$ , double deck, of which the upper layer is 6-lane expressway and the lower layer is used for light rail and public bus (see Figure 1). The 85m-span structure is combined with through and deck arch bridge, with rise-span ratio of 1/7,

double arch ribs design, each of which is made of single steel pipe with diameter of 170cm and wall thickness of 22mm, and the distance between the central-line of the two ribs is 10.4m (see Figure 2). The 190m-span structure is combined with through and half-through arch bridge, with rise-span ratio of 1/4, double arch ribs design. The section of the arch rib is truss combined with four steel pipes. The diameter of the main chord is 95cm, and the thickness of the wall is 22 ~ 24mm, and the height of the arch rib is 4.5m, with width of 2.6m, and the distance between the central-line of the two ribs is 29.4m (see Figure 3). All the arch rib steel pipes of sizes of spans were poured with C50 micro-expansion concrete. The substructure of this bridge is bored pile and pile footing, among them the pile diameter is 1.7m ~ 2m, with length of 70m ~ 100m.

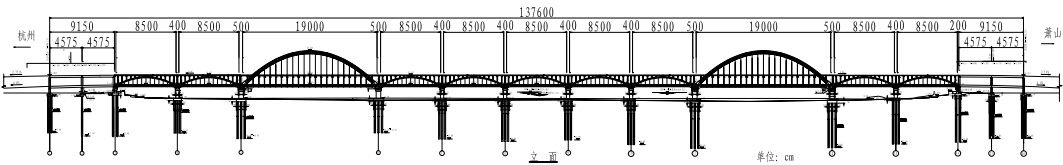


Figure 1: General elevation drawing of Qiantangjiang 4th Bridge of Hangzhou City, Zhejiang Province, China

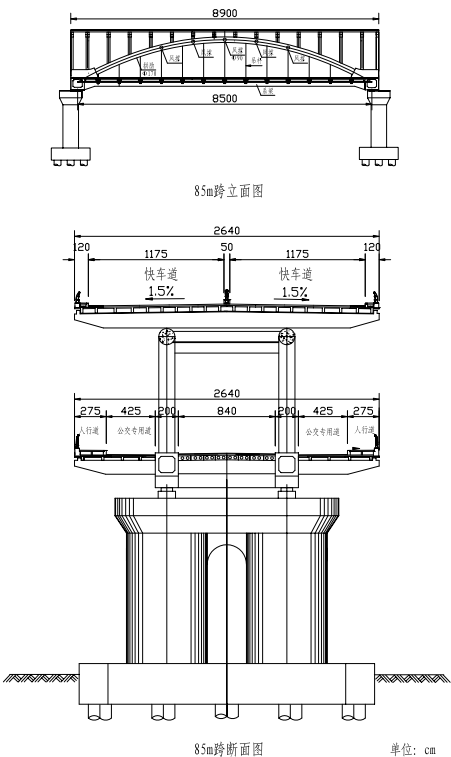


Figure 2: Structural drawing of 85m-span

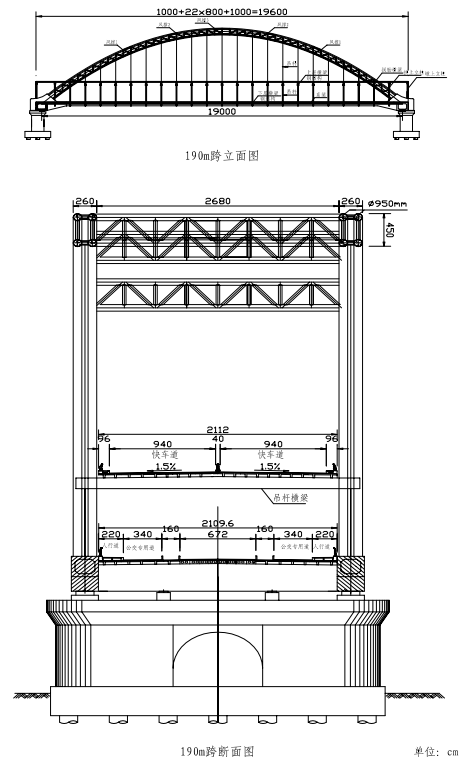


Figure 3: Structural drawing of 190m-span

### 1.2 Geology, hydrology and weather

The major composition of the covering layer of the bridge location are: loose and middle-sized powder, fine and middle-sized sand, fluid clayey sand, clayey loam, silt clay sand, gravel and round gravel. The underlying base rock on 1#~6# pier is Jurassic andesite, which belongs to

hard rock type, and the pile foundation was designed as per the bearing post. For the base rock on 7#~16# pier, it is malm siltstone, which contained gravel-sandy rock. The embedding of the base rock of this section is relatively deeper, and the rock is relatively soft, the pile foundation was designed as per friction pile.

The tide of Qiantangjiang river is world-famous, the tidemark around July is the lowest in each year, and it will reaches the highest in August, September and October, with the biggest tide range of 2.98m. The tide moves back and forth, the biggest average pressure caused by the tide to the pier is 45.0KPa, and the biggest momentary pressure approaches 70KPa.

Hangzhou City is one of the areas that easily attacked by typhoon and suffer great loss. Between July and August, influenced by Pacific typhoon, Hangzhou City always encounters fierce wind and storm. Typhoon will attack this area twice or three times each year, the biggest force can reach 12, with wind speed of 34m/s.

## 2. CONSTRUCTION OF SUBSTRUCTURE

### 2.1. Construction of bored pile in water

The biggest risk and difficulty the construction faced is the great effect of the tide of Qiantangjiang river, it's not reasonable to carry out operation on shipping and floating equipments. To guarantee the smooth construction and safety, the most effective method is to set steel trestle and bored pile above water which are strong enough to resist the impact of the tide (see Figure 4). The steel trestle was effective for connecting each construction platform and the land, and transporting construction materials, which can change the construction in water to construction on land. For the construction of the bored pile, except for the depth and rigidity of the steel sheath should meet the requirement for impact of tide, other constructions can be done as per normal routine.



Figure 4: Steel trestle and drilling platform

### 2.2. Steel cofferdam and steel sheath box

All the base slabs of Qiantangjiang 4th Bridge adopted low capped pile foundation design, and all the top of the base slabs are under the surface of the river. The construction of base slab adopted bottomless steel cofferdam and steel sheath box with bottom, to resist the great impact of the Qiantangjiang tide, all the steel cofferdam and steel sheath box in water adopted double-wall structure.

#### 2.2.1. Bottomless steel cofferdam

The riverbed that near the bank is shallow, so the piers adopted bottomless steel cofferdam to carry out construction in water. The shape of the steel cofferdam can be determined as per the

plane figure of each pier and tide-resistance requirement, octagon and hexagon were adopted, with wall thickness of 1.2m, which were welded with minitype steel plates. Settle certain number of supporting steel pipes in the steel cofferdam as per needs (see Figure 5).

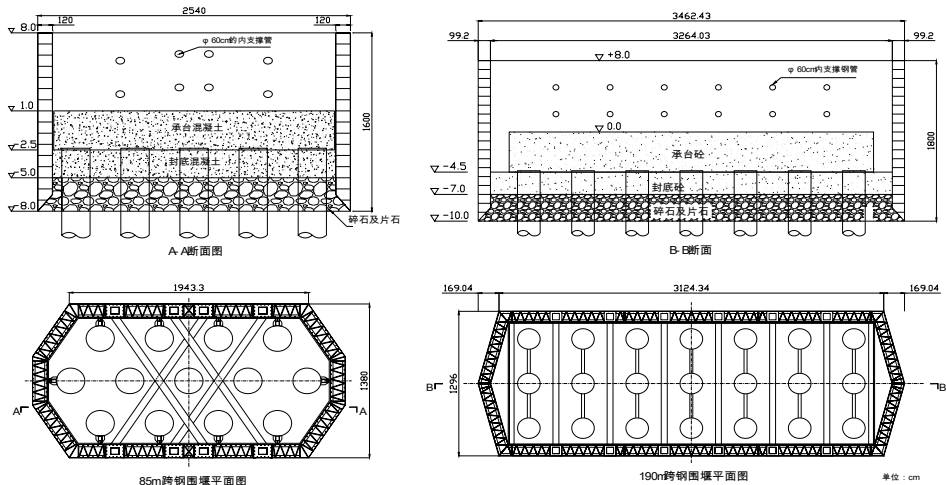


Figure 5: Structural drawing of steel cofferdam

The installation of the steel cofferdam was precast, which should be prefabricated and assembled on the bank, and all the members should be transported to each pier and platform should be assembled, and then assemble the steel cofferdam to a whole, at last sink the cofferdam to the designated place. During the sinking process, sand-blow method was adopted to guarantee the smooth arrival to the designed elevation place. Ripraps and crashed stone should be filled in the cofferdam and be leveled by the diver, and at last sub-sealing concrete was poured. After the sub-sealing concrete reached the design intensity, water should be pumped, and then start the construction of the base slab.

### 2.2.2 Steel sheath box with bottom

The riverbed that near the center of the river is deep, the bottom of the base slab is shallowly under the riverbed (remove the covering layer before sinking of the steel sheath box), so construction technics of steel sheath box with bottom was adopted. This technics effectively saved materials and quickened the construction process, but the resistance to the tide was weak, necessary strengthening measures should be taken. The sinking of the steel sheath box and the pouring of the sub-sealing concrete should be completed during period between two great tides. For the first time, this Bridge adopted steel sheath box with bottom as construction platform on Qiantangjiang River that with strong tide, and thanks to thorough consideration, this Bridge was successfully completed.

## 3. CONSTRUCTION OF SUPER SPAN UNSUPPORTED CABLE HOISTING AND INSTALLING

The superstructure of the main bridge of Qiantangjiang 4th Bridge mainly adopted construction technics of precast installation, of which the total weight of the required prefabricated members would be beyond 30000t. The site condition went against usage of large floating equipments, so based on consideration of kinds of factors, a super span unsupported cable hoisting and installing system was designed for installation of the superstructure of the main bridge.

### 3.1. General layout of this system

Based on the practical site condition and member installation requirements of each span, the span structure with three towers and four cables was adopted in the cable hoisting and installing system, and the cable-span combination is 250m+690m+650m+250m. Two towers were set respectively near 2# pier on Hangzhou bank side and 16# pier on Xiaoshan bank side, and the middle tower was set on 9# pier. The height of the towers on both sides is 120m, and the width is 42m, the height of the middle tower is 104m, and the width of it is 46m (see Figure 6). This system adopted double cables on upper and lower reaches, these two cables are independent, and the hoisting point between these two cables is independent. Both of these two cables adopted separate hoisting, towing, roadster, upper and lower suspending system, there are 4 sets of hoisting points altogether in the bridge. The design hoisting weight of each cable is 650KN, and the total design hoisting weight is 1300KN. Movable cable saddle was adopted, and the main cable and hoisting point can be transversely moved through moving the cable saddle.

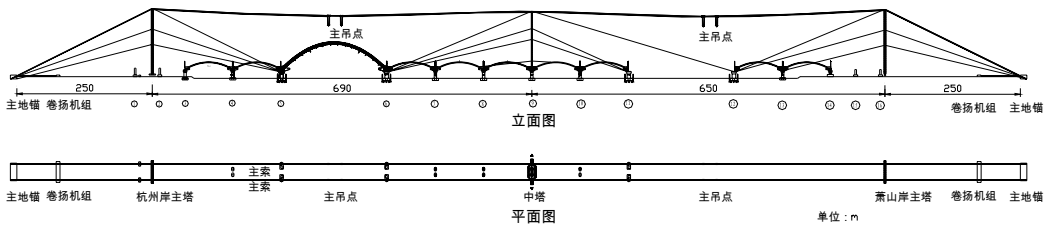


Figure 6: General layout chart of the unsupported hoisting and installing system

### 3.2. Composition of cable hoisting and installing system

The main cable adopted  $\phi 50$  sealed steel wire rope, each cable was composed of 7 steel wire ropes, with total length of each of 2100m. There are 14 main cables altogether in this bridge. The sealed steel wire rope was composed of high-tensile steel wires. The design vertical degree of the main cable is 1/16, and the safety factor was no less than 3.0.

The height of the side towers is 120m, and the width along the longitudinal direction of the bridge is 4m, and the width along the transverse direction of the bridge is 42m. The net height of the middle tower is 104m, and the width along the longitudinal direction of the bridge is 2m, and the width along the transverse direction of the bridge is 46m. The side towers and the middle tower all adopted universal members to assemble, and the bottom adopted hinged structure (see Figure 7).

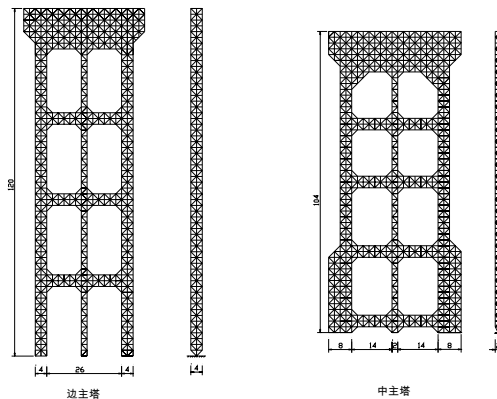


Figure 7: Sketch map of the structure of the main tower of the hoisting and installing system

### *3.3. Design and application of the cable hoisting and installing system*

It took 4 month to install and adjust the cable hoisting and installing system, and the hoisting and installing of the superstructure members was started after testing hoisting with 1.3 times of the hoisting load was carried out. The 85m-span was hoisted by three sections (each span was divided into 6 sections, which were transversely connected with 5 steel pipes). Common steel cable-stay system was adopted, and the four sets of hoisting points were installed at the same time. 1 span took 1~2 days to complete installation. The 190m-span was hoisted by thirteen sections (each span was divided into 26 sections, which were transversely connected with 5 steel pipes). Steel strand cable-stay system was adopted, and the cables on upper and lower reaches were installed alternately. After assembling, loosen the cable and the arch was formed. Averagely, each span took 18 days to complete installation. After hoisting all the members, the hoisting and installing system was removed in Apr., 2004. During this period, this system endured attacks of strong typhoon, which guaranteed the smooth completion of this bridge.



Figure 8: Full view of cable hoisting and installing system of Qiantangjiang 4th Bridge

## 4. CONSTRUCTION OF CONCRETE JACKING IN STEEL PIPE WITH CONCRETE PUMP

The main bridge of Qiantangjiang 4th Bridge contained 11 steel pipe concrete tied arches, 34 steel pipe arch rib chords, and the quantity of the concrete in the steel pipes was more than 6500m<sup>3</sup>. At the same time, the diameter of the 85m arch rib steel pipe reached 1.7m. It's the first time in China to complete jacking the filling concrete at one time in steel pipe with such great diameter, moreover, the steel pipe concrete arch rib was the major working member, so how to pour concrete in pipes and how to guarantee the filling quality of the concrete in steel pipes is on of the key points to the success or failure of this bridge.

### *4.1. Mix design of the concrete*

For the filling concrete in steel pipes, except the intensity of it should meet the design requirements, it should also has such characteristics as retarding, early strengthening, auto-sealed, slow collapse degree, low contraction, and fine pumpability, etc. Based on the peculiarity of the local materials, and after optimal design, the mixture ratio of the filing concrete was finally determined. The major indexes of it were: R7=53.1Mpa, R28=60.6Mpa, slump constant should be 22±2cm, and the loss of slump constant within 3 hours should be no bigger than 3cm, the initial setting time should be less than 10 hours, and the free swell (FS) should be 0.04%.

### *4.2. Jacking method to pour the concrete to the top of the steel pipe*

The filling concrete of the steel pipes was jacked at one time with high pressure concrete pump from abut to the crown of arch. The pump was settled near the trestle (see Figure 9), using  $\phi 125$ mm high pressure duct to connect with the steel pipes of the abut (see Figure 10). The connector should set stop valve to prevent backflow of concrete. Diaphragm was set in the top pipes, and two discharge pipes were vertically welded on both sides of the diaphragm. The concrete was symmetrically pumped into the steel pipe arch rib, and after 3~4 hours' continuous

pumping when the quality of the discharged concrete was almost the same as the one on the entrance, the pouring work can be completed.



Figure 9: The concrete was pumped from both sides of the abut into steel pipe arch rib



Figure 10: The workers were connecting the concrete duct

The construction of filling concrete was completed smoothly, for the 85m-span, two steel pipes (equivalent to 1 span) can be poured in one day, and for the 190m-span, 4 steel pipes (equivalent to 1/2 of 1 span). The whole concrete pouring work of this bridge just took more than 20 days, with obvious effect. During the implementation process, the pump pressure was kept at a low level, which proved that construction technics of continuously pump filling concrete into steel pipes is feasible in construction of concrete-filled steel pipes with large diameter.

## 5. CONCLUSION

- 5.1 The most effective scheme for construction of substructure of bridges on rivers with strong tide is to set steel trestle and construction platform above water that can resist the impact of the tide, which change construction in water to construction on land.
- 5.2 Based on embedded depth in the covering layer, it's safe and feasible to adopt steel sheath box with bottom or steel cofferdam as soon as effective measures are taken in the river with strong tide.
- 5.3 The superstructure construction adopted large-span unsupported cable hoisting and installing system, which played great role in installation of more than two thousand members.
- 5.4 For the construction of concrete-filled steel pipes, in aspects of the diameter of the steel pipes and the concrete pouring quantities, they were the number one in the China. The

smooth completion of this bridge proved that the construction technics of continuous jacking concrete method is feasible, and moreover, the success of the jacking of the 85m-span with diameter of 170cm proved that it's also feasible for construction of large-diameter concrete-filled steel pipes.

- 5.5 The whole construction of Qiantangjiang 4th Bridge just took two and a half year, this project won Lu Ban Award (the highest prize in Chinese construction industry) and Zhan Tianyou Award (the highest prize in Chinese civil engineering).