CAIYUANBA BRIDGE, CHONGQING, CHINA

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Abstract

The Caiyuanba Bridge over the Yangtze River, located between Yuzhong and Nanan districts has a main span of 420m, and was the world’s longest arch span for dual highway and rail traffic at the time of its completion in 2007. The bridge carries six lanes of highway traffic on its upper deck and two tracks of monorails on its lower deck. This paper presents the key design factors and solutions in the design and construction of this tied-arch bridge.

Key words: Caiyuanba Yangtze River bridge tied-arch bridge; dual highway and rail bridge; construction.

1. Introduction

Chongqing is a city in the mid-western region of China. Chongqing has a population of 32 million. In 1996, the city was annexed from the Sichuan province and became one of four independent municipalities that report directly to the central Chinese government. Granted the same jurisdictional rights as other provinces, this has allowed the city more rapid development. Chongqing has acted as a leader in infrastructure development in western China.

The City is surrounded by mountains and is divided by several major rivers: the Yangtze, the Jialing, and the Wujiang. Consequently, there has been a need to construct many major bridges, both for
highway and rail traffic to connect the areas. Today, Chongqing boasts the most major bridges in China. It is often called the “Bridge Capital of China.” The metropolitan area of the city is bisected by two major rivers, the Yangtze and the Jialing, shown in Fig. 1. As of today, most transit bridges are designed as dual purpose structures that carry both highway and rail.

Fig. 1 Metropolitan Chongqing

Fig. 2 Chongqing Transit Plan

Planners are now developing a total of 513km of transit line. There are a total of 9 lines plus one ring line, as shown in Fig. 2. 19.15km of monorail with 18 stations of Line 1 were opened for operations on June 18, 2005. This is the first operating monorail in China. There are 131.86km of transit lines under construction by the end of 2009. Lines 1, 2, 3 and 6 will be complete by 2014; Lines 4 and 5, by 2020. The entire system will be complete by 2050. Among them, Lines 1 and 3 are monorails. The rest of the transit lines are dual rail.

2. The Bridge

The Caiyuanba Bridge over the Yangtze River is a vital transportation link between Yuzhong, the central district, and Nanan, the southern district. It carries six lanes of highway on its upper deck and two tracks of monorails on its lower deck. The 420m span is thus the world’s longest arch span for dual highway and rail traffic, when it was opened to traffic in 2007.

Besides the tied-arch main spans, there are the southern and northern approaches, the Sujiaba Interchanges connecting the main bridge to the southern shore, and the Caiyuanba Interchange connecting the main bridge to the northern shore. The Waterway Department of the Ministry of
Communications determined the main span length, based on the navigation requirements of the waterway. The 420m navigation clearance is much larger than the clearance in Shibanpo because it is located in a curved portion of the river.

Because the bridge is very visible from most parts of the City, aesthetics was an important factor for the design. Various bridge types including cable-stayed, suspension, arch, and truss bridges were studied during the conceptual design stage. But the City and general public preferred an arch bridge. A panel of bridge experts appointed by the Owner, selected the half-through tied-arch scheme, as shown in Fig.3.

Because of its mountainous nature, during the rainy season, the water level of the Yangtze River in Chongqing can rise up to ±3m. The arch is supported by four concrete columns, such that the arch will not become submerged during high water season. Constructing a concrete lower portion of the bridge offers additional and better protection against possible barge collision and corrosion.

The required depth of the girder is about 11m in order to accommodate the monorail on the lower level. Because this type of deep girder is very rigid, it is possible to make the arch ribs relatively slender.

2.1 Arch

China has built many concrete-filled steel tube arch bridges. This type construction was also considered at the preliminary design stage. However, aesthetically, a bridge in such a delicate location should look as light as possible so as not to spoil the view of the City. Consequently, it was decided the arch ribs
should have a box-shaped cross section. The arches are further inclined inwards in a basket handle shape to achieve a more slender appearance. This inclination also improves the stability of the structure, as shown in Fig. 4.

Chongqing is well known for having thick fog year round. Yellow and orange red are the two most suitable colours to make the arch more visible in the fog. The Owner finally selected the orange red colour for the bridge.

2.2 The Truss

The truss is 11m deep to provide sufficient clearance for the monorail, the loading of which is among the highest in the world, as shown in Fig. 5. The truss is spanning the end spans without intermediate vertical struts. This is possible because the deep truss itself has sufficient stiffness to span the 102-meter side spans. Deletion of vertical struts in the end spans makes the bridge look much more graceful.
An 11m-deep girder crossing the skyline of the Yangtze Valley looked bulky. For this reason, a steel truss was chosen over a box girder as it appears lighter. In addition, a truss offers a better view for monorail passengers. To further lighten the appearance, a trapezoidal cross section for the truss girder was selected, as shown in Fig. 6. The tapered edges of such a girder make the girder look much thinner.

The truss is a Warren-type truss. The hangers are 16m on centers. At each hanger point, an inclined strut brings the vertical load from the hanger back to the truss. The hangers are anchored to an extension of the floor beams of the deck.

The truss is continuous over five spans. Extending the truss to five spans offers the bridge a more harmonious appearance. At the intersection with the arch ribs, the truss is suspended by cables from the concrete frame. The approach spans are concrete box girders.

With six lanes of highway traffic and one pedestrian path on each side, plus barriers and space for the hangers, the total width of the bridge deck is 39.318m out to out. The deck is a steel orthotropic plate with floor beams spaced at 4.00 meters on centres. The ribs are trapezoidal and are 8mm thick. The deck plate is in general 16mm thick.

Box sections are used for the bottom chords. Most diagonals have an H section. Shop splices are mostly welded and field splices are bolted using high strength bolts.

At the lower level, the bottom chords are horizontally braced. Transverse floor beams at 16-meter spacing support the steel box-shaped rails for the monorail.
2.3 Y-shaped concrete frame and foundation

The lower portion of the arch is a concrete frame. Concrete was selected to provide better resistance to possible barge collisions. Aesthetically, the heavy concrete frame also makes the structure look sturdier. The outside legs of the concrete frame are anchored vertically with vertical ties that are adjustable so that a known vertical tie down force can be assured, as shown in Fig. 7. The front legs of the concrete frame penetrate above the deck so that the connection between the concrete legs and the steel box ribs is located above the deck level. Horizontal ties are placed at the deck level to stress the legs together. These ties are adjustable. The concrete frames are prestressed using strand tendons.

The upper portions of the arch ribs are steel box sections, 2.40m wide and 4.00m deep, constant along the entire length. Diaphragms inside the ribs are provided to stiffen up the hollow box section. Longitudinal stiffeners are simple plates. The box ribs are delivered in sections and welded together at the site.

![Fig. 7 Force Diagram of the Concrete Rigid Frame](image)

The hangers are parallel wire strands with Hi-Am type sockets. The upper end of the hangers penetrates the bottom plate of the arch rib and is anchored at a diaphragm inside the box rib. The bottom end of the hangers is anchored to the deck with eye sockets. The hangers are located in the same centre plane of the arch ribs.

The ties are made up of high-strength, seven-wire stands. They are individually sheathed. Each tie is divided into three sections. The centre section anchors at the inside legs of the concrete frames, while
the other two connect the inside and outside legs. Each tie can be individually stressed. Each strand can also be individually replaced without interrupting traffic.

Both hangers and ties are made to meet the same standard for stay cables in cable-stayed bridges and must provide the same level of safety and durability.

The soil is generally solid rock. The foundations are supported by 3.00-meter-in-diameter short caissons.

2.4 Monorail

The rail girder for the monorail was installed after the bridge was complete, as shown in Fig. 8. The rail girder is made up of steel box sections spanning 16m. They are directly supported by the cross girders, which are also placed at 16m apart. The Caiyuanba Bridge is a component of Transit Line 2, which is not yet complete. Hence, the bridge does not yet carry trains.

The monorail wagon is typified by the one shown in Fig. 9.

3. Construction

During the high-water season, the Yangtze River is very turbulent and can rise more than 30 meters above the low-water level. Building the foundation during the high-water season would have required very heavy cofferdams, the cost of which was prohibitive. Therefore, the foundation was completed during the dry season. To expedite construction, all caissons are hand dug at the same time. Because
work on all caissons was done simultaneously, only the one longest pile is on the critical path. Fortunately, this was not a problem in China as labour was readily available.

As mentioned above, Chongqing is a hilly city and the streets are narrow and winding. Transportation of construction materials through the city was not possible. Thus, all materials, including the steel sections of the girder and the arch ribs were delivered to the site on barges via the Yangtze River. One challenge was that the difference in water level between barge and land made docking and handling very difficult. In addition, the navigational channel is located on one side of the river during the dry season. So, it was difficult to access from the other side of the river. Consequently, it was decided to use a heavy-duty, double-high line to lift and erect the steel sections directly from the barges, as shown in Fig. 10. The design capacity of the high line is 420 tons. But the actual weight to be lifted was less than 350 tons. The high line was load tested before the sections were lifted.

![Fig. 10  Construction with High Lines: Before and after Girder Closure](image)

The arch ribs were erected first using the high lines and a temporary cable-stayed system with its pylons located above the main piers. The high lines lifted the steel sections off the barge in the navigation channel, close to the southern bank, and they were transported to construction sites on the main span. The swift erection of the arch ribs averaged 3 days per one pair of 16-meter section.

After the arch ribs were erected, a temporary tie was installed to equalize the horizontal thrust of the arch ribs. The girder was then erected using the same high lines, cantilevering from both ends and suspended immediately from the arch ribs by the hangers. The sections of the truss were bolted together
in the field, averaging about 7 days per pair of 16m sections. The closure of the girder at the mid span went very smoothly.

The ties were installed and stressed after the truss was complete.

4. Standards

The bridge was designed according to Chinese specifications. For the orthotropic deck, the design criteria were supplemented by the AASHTO-LRFD specifications. For the hangers and ties, the design was supplemented by Post Tensioning Institute’s “Recommendations for Design and Installation of Stay Cables.” Chongqing is not a seismically active area. Therefore, seismic nor wind elements were considered for this structure.

5. Remarks

The bridge was opened to highway traffic in October, 2007. Aesthetic lighting was installed. The bridge is a beautiful addition to this “Bridge Capital of China.”