

Design of a Rigid-frame Steel Truss Arch Bridge

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Keywords: Xinguang Bridge, Steel truss arch, Triangular rigid frame, Horizontal ties, Vertical Suspender.

Abstract. The Xinguang Bridge, crossing the shipping channel of the Pearl River in the city of Guangzhou, is a three-span continuous half-through rigid frame steel truss arch bridge with two RC V-shaped triangular rigid frames. The paper first gives a brief introduction on the important engineering aspects. Then the characteristics of this bridge such as the supporting system, structure of the deck system, horizontal tie, arch rib, vertical suspender, V-shaped triangular rigid frame, and foundation are investigated herein are given detailed demonstration. The conclusions and future prospects are finally presented.

1. Introduction

The Xinguang Bridge, crossing the shipping channel of the Pearl River in the city of Guangzhou, is a three-span continuous half-through rigid frame steel truss arch bridge with two RC V-shaped triangular rigid frames [1] (See Figure 1.). The bridge has a total length of 1083.2m. The total length of 3 spans of the main bridge is 177m+428m+177m=782m. The main bridge is 37.22m wide for six traffic lanes and two sidewalks. When it was open to traffic in January 2007, Xinguang Bridge had the 6th-longest arch span in the world and had the 3rd-longest arch span(428m) in China. The general data for design is presented in Table 1.



Figure 1. Illustrative view of Xinguang Bridge

2. Special Aspects of the Design of the Main Bridge

The Xinguang Bridge, crossing the shipping channel of the Pearl River, is located in the central axis of Guangzhou New City. The design of the bridge was dominated by the aim to develop a landmark. By a close cooperation between the owner, the design engineer and the construction engineer, a harmonic design of the entire crossing has been achieved. The bridge, which spans the Pearl River like a flying rainbow representing the development of the economies in Guangzhou, incorporates a number of innovations and first applications in China like the special bridge structural system, non-conventional constructional details, and the erection method. The special design aspects of major importance can be summarized as follows.

Table 1. General data

Design speed:	80km/h
Design load:	Vehicular load: Truck-20T Trailer-120T Crowd load:4.0kN/m2
Design wind speed:	27.9m/s
Length:	1083m
Width:	37.22m, with 12.0m wide roadways for 3 vehicle lanes and 3.0m sidewalks in each direction
Span length for main bridge:	177 m +428 m +177 m =782m
Span length for approach	50.4 m +50 m +50 m (north), 50 m +50 m +50.4 m (south)
Clear height for shipping channel:	34.0m
Clear width for shipping channel:	210.0m
Design water level:	8.13m
seismic fortification intensity:	VIII
Material type:	Superstructure: Primary member for steel structure: Q345qC Secondary member for steel structure: Q235C Node plate for arch rib: Q345qE Concrete class: C50 Substructure: Concrete class for pile foundation: C30 Concrete class for pile cap: C40
Materials used:	Concrete: 100,000m3 Bar, wire and strand:14000 t Structural steel for main bridge: 13,850 t Construction temporary steel: 15,000 t

2.1 Foundation

Foundations for the main bridge are supported on end-bearing cast-in-place bored piles anchored in solid rock layer. As shown in Figure 2, in the case of main span, the foundation consists of 36 bored tube bored piles of 2.6m diameter, and the pile cap has a size of 48.3m in transverse direction, 34.7m in longitudinal direction of the bridge, and 6m in thickness, while for the side span, each of the two tie-down pile caps having a size of 11.6m by 11.6m and thickness of 3.5m are supported by 9 cast-in-place bored piles of 2.0m diameter.

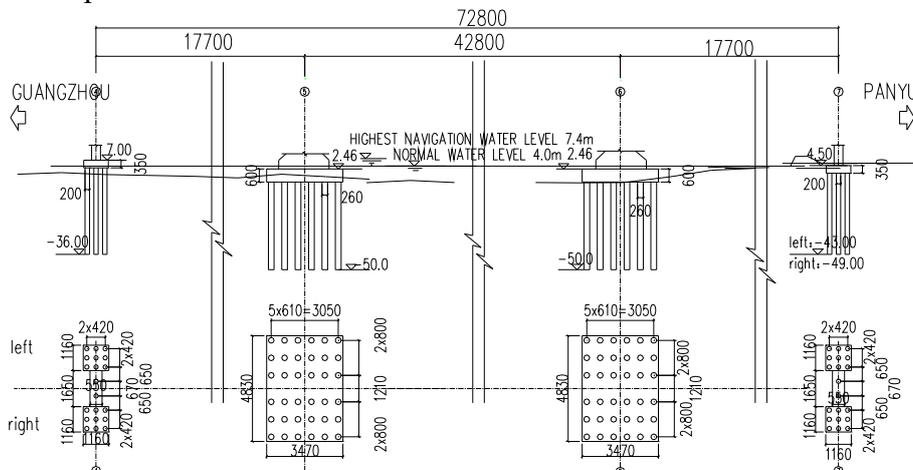


Figure 2. Elevation view and top view of foundation (unit:cm)

2.2 V-shaped Triangular Rigid Frame for the Main Pier

The V-shaped triangular rigid frame (See Figure 3) as the connections between the center span and side spans provide large stiffness, good seismic performance, and better resistance against possible ship collision capability [2]. In addition, the rigid frame provides its capabilities in resisting the

moment imbalance in construction, which simplified the construction procedures and decreased the live load influences between side span and main span. The tied beam of the triangular rigid frame is a PC solid L cross-sectional structure with a width of 5600mm and a height of 3000mm. 34 post-tensioned, injected tendons are installed into the tied beam of the frame, and each tendon consists of 31-7 ϕ 5 strands.

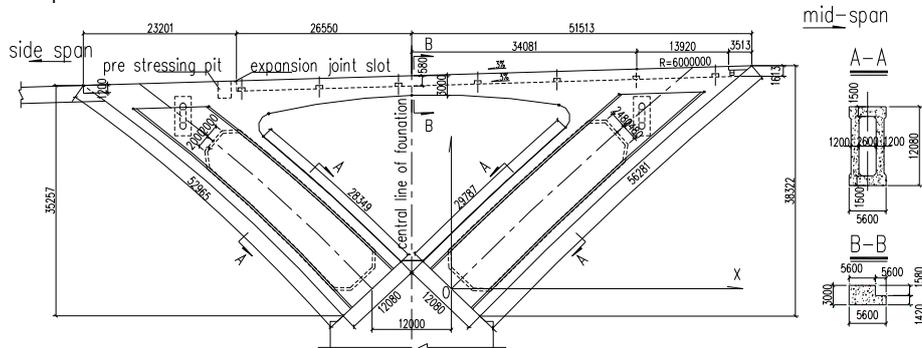


Figure 3. Elevation view of Triangular Rigid Frame (unit: mm)

2.3 Arch Rib

The arch ribs of the mid-span with a span of 428m (clear span length: 416m) and a height of 104m follow a catenary with an arch axis coefficient of $m=1.2$ and a ratio of rise to arch span to of $1/4$. These two steel arch ribs are spaced at an interval of 28.1m from centerline to centerline. Each of these arch ribs has a depth varying from 7.50m at the crown to 12.0m at the spring. The top and bottom chords with rectangular box girder cross-sections have thicknesses of 30mm and 50mm for steel webs and thicknesses of 32mm, 40mm, 50mm for the top and bottom plates of the girder. [3]

The steel arch ribs of the side span with a span of 177m (clear span length: 171m) and a height of 56m follow a 3-order parabola with a depth varying from 7.50m at the crown to 12.0m at the spring. The steel box girders of the cross section have thicknesses of 24mm, 32mm and 36mm for steel webs and thicknesses of 30mm, 36mm, and 40mm for the top and bottom plates of the girder, respectively.

The integrated node connection technique is employed to fabricate the steel arch ribs. The chords of the arch ribs, as a welded and bolted structure, are connected in the node position via an integrated node plate which is formed by changing the height and thickness of the steel webs. The longitudinal ribs inside the steel box girder and cross section of arch chord are connected using high-strength bolts and field welding, respectively, while the braces are connected to the chords via high-strength bolts.

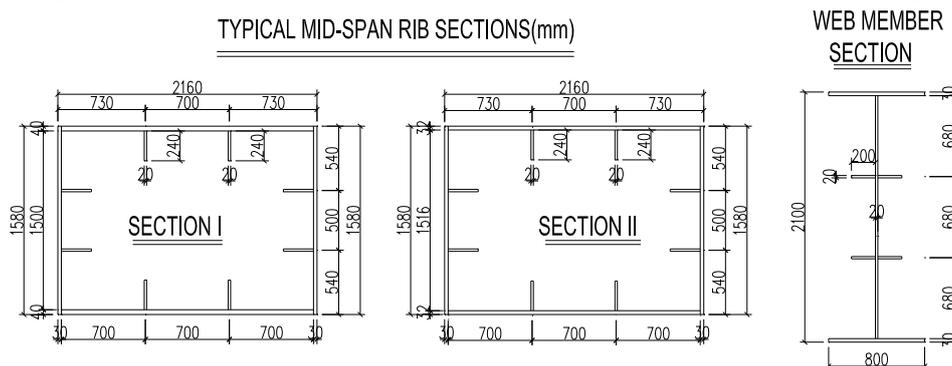


Figure 4. Typical cross section of the arch ribs of main span (unit: mm)

2.4 Horizontal Ties

8 adjustable OVM horizontal ties with 199- ϕ 7 parallel steel wires, Hi-Am type sockets, and stress-released protection HDPE layer are placed at the deck level between the two ends of each arch rib of mid-span to balance the horizontal force induced by arch rib. The tie cables can be replaced one by one. 16 post-tensioned, injected tendons are installed into each PC longitudinal beams (also as the horizontal ties) of side span, and each tendon consists of 27-7 ϕ 5 strands. The stiffened horizontal tie has a height of 2500mm and a width of 2100mm.

2.5 Vertical Suspender

The new types of OVM cable system, composed of galvanized parallel wire strands, Hi-Am type sockets, and stress released HDPE protection layer, is employed for the vertical suspenders. The upper end of each suspender penetrates the bottom plate of the arch rib and is anchored at a diaphragm inside the box rib while the bottom end is anchored to the transverse beam. Two short suspenders in each end of the main arch and side arches are specially designed to be a hinged and enlarged structure capable of releasing the deformation and horizontal displacement and decreasing its stress amplitude. The suspenders in the center and end of the main span consist of 139- ϕ 7 and 187- ϕ 7 galvanized parallel steel wires, respectively. In the case of side spans, the suspenders in the center and end of the span consist of 187- ϕ 7 and 313- ϕ 7 galvanized parallel steel wires, respectively.

2.6 Bearing System of the Main Bridge

Compared with the conventional “flying-bird” three-span arch bridge with a half-through center span, two side spans under deck, and horizontal cables balancing the horizontal thrust of the center arch span, the innovative structure of the main bridge introduces the V-shaped triangular rigid frame as the connections between the center span and side spans. As shown in Figure 1, one end of the side arch is fixed in the V-shaped triangular rigid frame, while another end is supported on the side pier via a movable spherical steel bearing capable of 200mm longitudinal displacement, which makes it possible to release the thermal stress with the help of deck expansion joint. Moreover, the chord members of arch ribs of the main span are directly embedded in the triangular rigid frame, which can significantly enhance the structural stiffness and makes it no need to install the expensive bearings. [4].

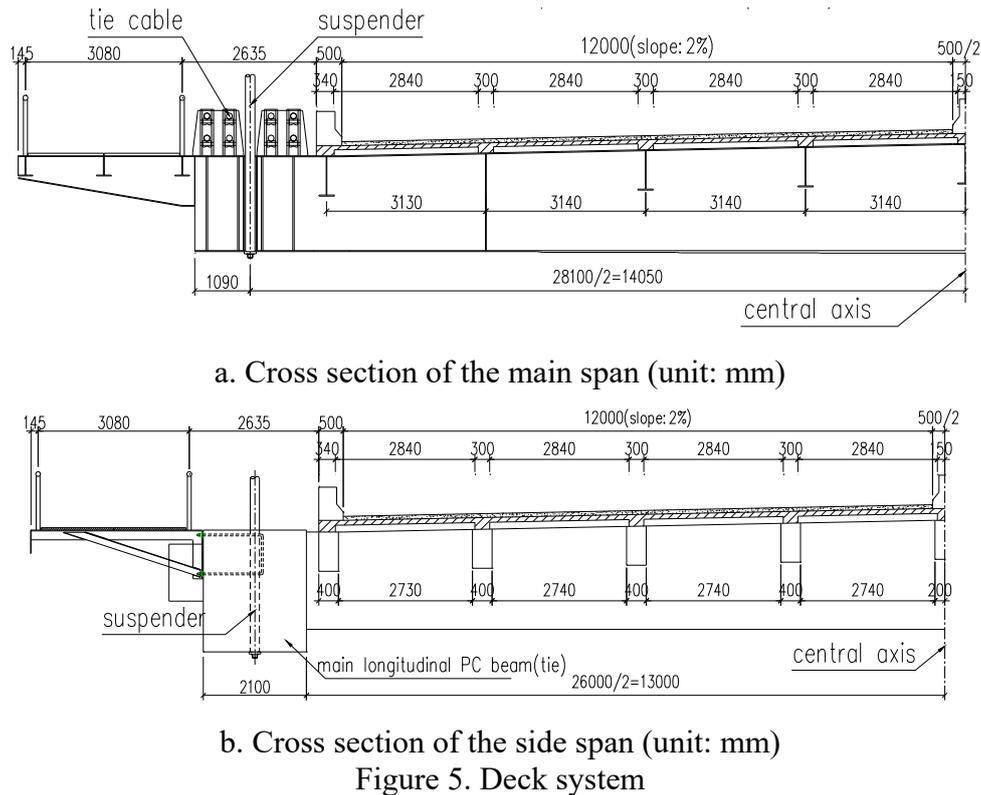
2.7 Deck System of the Main Span: Semi-floating System

The novel structure can fully take advantage of not only the superior capacity of load carrying system of the steel truss arch but also the large stiffness and good seismic performance of the triangular rigid frame. Note that the horizontal stiffness of the rigid frame is notable. To release the structural thermal deformation-induced strong horizontal force of the deck system the deck structure of center span of the main bridge is designed to be a horizontal movable semi-floating system in the longitudinal direction. The deck structure is designed to be supported by steel transverse beam via suspenders hanged to ribs and by spherical steel bearing to triangular rigid frame. Furthermore, two expansion joints between the deck connection of center span and side span are installed to release the thermal stress.

2.8 Structure of the Deck System

As shown in Figure 1, to attain to an ideal moment balance of the triangular rigid frame and the foundation, the longitudinal beam and the lateral beam of the two side spans are designed to be a prestressed concrete structure, respectively, whereas those of the main span are carefully designed to be steel structure. The expansion joints are the borderlines of the side decks and mid-deck. [5]

As represented in Figure 5, the deck structure of the main span is a lattice girder system which is made up of 41 steel transverse beams and 9 steel longitudinal beams. The pre-cast reinforced concrete slabs are then rigidly connected to the lattice girders to form a steel-concrete composite structure. The webs and bottom wings of the steel longitudinal beam are field bolted using high-strength steel bolts while the top wings of them are field welded to the transverse beam. In the case of side span, the stiff PC tie (also regarded as the longitudinal beam), the PC transverse beams, the secondary longitudinal RC beams, and RC bridge slabs are employed to enhance the structural stiffness of the deck system.



3. Conclusion

An innovative design for the Xinguang Bridge was developed on the basis of the traditional half-through truss arch bridge solution, incorporating the typical V-shaped triangular rigid frames. The shape appearance, color application, and structural mechanic characterization are carefully considered to design a novel structure. Consequently, the design of Xinguang Bridge illustrative a valuable example to other long-span arch bridge's design.

Acknowledgments

Foundation item: Natural Science Foundation of China; State Key Laboratory of Subtropical Building Science, South China University of Technology; supported by the Fundamental Research Funds for the Central Universities.

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