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DESIGN OF MAIN BRIDGE OF CHAOTIANMEN YANGTZE RIVER BRIDGE

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Abstract: *The main bridge of Chongqing Chaotianmen Yangtze River Bridge is a half-through steel tied truss arch with total length of 932m and a span arrangement of 190+552+190m. Its main span is 2m longer than the current span record of 550m of steel arch bridge held by Lupu Bridge in Shanghai. The Chongqing Chaotianmen Yangtze River Bridge has double decks. The upper deck is 36.5m wide with six lanes and two sidewalks. The lower carries two lines municipal light railways and two lanes to either side. The steel truss of side span is installed by means of cantilever method with the assistance of provisional supports; the steel truss in middle span is installed using sling pylon, by cantilever method, closed at center of the span. This paper mainly describes the structural design, static and dynamic analysis, anti-corrosion coating system of steel truss, and installation procedures of the long span half-through steel tied truss arch.*

1. GENERAL INTRODUCTION

The Chongqing Chaotianmen Yangtze River Bridge is located 1.2 km downstream Chaotianmen in Chongqing, China. This bridge is an important passage connecting the central urban business regions on both banks of the Yangtze River. Total length of the bridge is 1741m, of which the 932m main bridge is a (190+552+190) m half-through steel tied arch truss structure; the 314m northern approach bridge and 495m southern approach are all prestressed concrete continuous girders.

The bridge has double decks, of which the 36.5m upper deck has dual three-lane and sidewalks on both side, and the lower carries two lines municipal light railways and two lanes to either side (Figure 1).

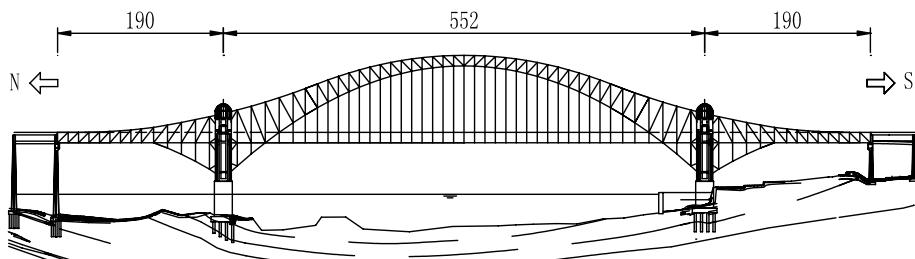


Figure 1: General layout of the main bridge (unit: m)

2. MAIN DESIGN CRITERIA

The bridge is located in a trunk road with I highway grade. The design vehicle speed is 60Km/h;

Bridge cross-section: dual three-lane on upper deck; two lanes on lower deck; sidewalk width outside truss: $2 \times 2.5\text{m}$

Light rail standard: dual lines, line spacing is 4.2m; design train speed: 80Km/h~100 Km/h

Clearance of Light Rail: clean width $\geq 9.2\text{m}$; vertical clearance over rail top not less than 6.5m

Design traffic load: traffic load as Highway grade I, checked with urban—A load;

Light rail load: Type B train, a train team includes five trains

Crowd load: the load value is 2.5 kN/m² for purpose of general calculation, 4.0 kN/m² for local components analysis

Wind load: Maximum wind speed is 26.7m/s

Thermal forces: Max. Temperature: +45°, Min. Temperature: -5°; system mean temperature is 20°, temperature difference considered as $\pm 25^\circ$.

3. STRUCTURAL DESIGN

3.1 General layout and main structural characteristics

The main bridge is a three span continuous steel tied arch truss structure with a span length of 190+552+190m and a width of 36.5m. The main truss with two pieces of truss is 29m

wide. The end span is a steel truss of variable height, and the middle span is a tied steel arch truss. The height between the arch top and the middle support is 142m, the outline of the lower arch chord is a quadratic parabola with 128m arch rise, and the rise-span ratio is 1/4.3125. The upper chord of arch is also a quadratic parabola transitioning to the circle curve of 700m radius on upper chord of end truss span. The main truss adopts “N” shaped truss of variable height, the arch truss height is 14m at mid-span, 73.13m at middle pier(stiffened chord of arch rib is 40.65m), and 11.83m at end pier. Due to the big difference of arch truss height, considering general arrangement and the aesthetic factor, the truss panels have three lengths: 12m, 14m, and 16m.

Two levels of ties are set in the middle span, at 11.83m spacing. The upper tie is not through the whole main truss and only connected to the lower arch chord; while the lower tie goes through the whole truss including the middle chord at the stiffened leg and the lower chord in the end span. The upper tie is “H” sectioned; and the lower tie has “王” shape section assisted with cables. The steel tie end is connected to the lower chord panel joints of arch rib, assistant cables to be anchored at end node of the tie. The function of assistant cables is to reduce the forces of lower steel tie, so as to optimize the dimensions of steel components.

The support system of main bridge adopts hinged bearing system. In longitudinal direction, hinged fixed bearings are arranged at middle pier on north side, and movables on the rest piers. In transversal section, fixed bearings are arranged on the middle support, and movables on side supports, two transversal restrictions bearings are designed at the middle of the lower crossbeam of side supports. The central transversal restrictions can make the transversal displacement induced by thermal forces of main truss to both sides well-proportioned, so as to avoid the rail deformation. The main bridge has spherical cast steel hinged bearing system with huge capacity; the maximum bearing force for middle support is 145000KN, which has the largest bearing capacity in China.

3.2 Main truss members

All of the main truss members are welded box section. To adapt the large inner force variety of the chord, the height and width of chord members section are variable correspondingly; the section width has two types: 1200mm and 1600mm, with section height varies between 1240mm and 1840mm. The members are spliced at four sides; to make the splicing convenient, the members have uniform height and width at splicing joints. For a member, the height and width don't vary at the same section.

To adapt well to different forces, the web members adopt “H” or “王” shaped sections. The upper tie bar has welded “H” shaped section; while the lower tie adopts “王” shaped section with assistant cables, four cables are set for each truss, each cable comprises 55 wires with filling epoxy coating. The suspension rod adopts parallel wires cables. The suspension rod has double hanging bars for the convenience of replacement.

3.3 Main truss panel joints

The panel joints of main truss have their particularities due to structural characteristic, so splicing panel joints are preferred to reduce manufacture difficulty and save engineering costs. However, the panel joints forces at middle support are very concentrated, and the

adjacent members have large dimension and thickness, so monolithic panel joints are adopted here; splicing panel joints are adopted on the rest parts of main truss.

3.4 Deck System

The orthotropic steel plate is applied for upper deck and lower deck system. The steel plate is 16mm thick, with closed “U”-shape ribs. Steel diagrams at an interval not exceeding 3m are arranged longitudinally. The upper deck has six longitudinal girders in its cross-section; the lower deck has two longitudinal girders respectively on each side, and transversal girders to be set at main truss panel joints. Stringers and cross beams system to be adopted for the light rail part on the lower deck, there are two sets of stringers at 4.2m spacing for the light rail, each set of stringer comprises two pieces of stringers, plane bracing, and lateral bracing. On the upper deck, sidewalk brackets are to be set outside main truss panel joints, and “Π” shaped orthotropic steel plates to be laid on the brackets. The section is shown in Figure 2.

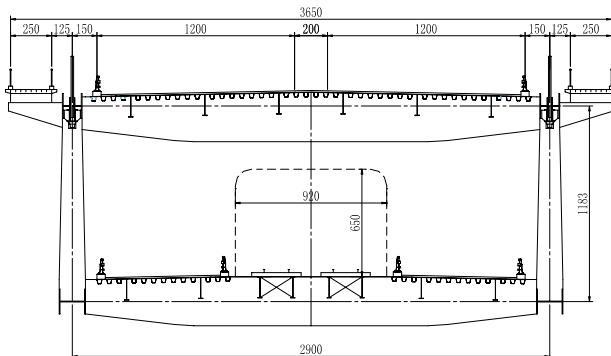


Figure 2: Main truss section and bridge deck

3.5 Bracing system

The plane longitudinal bracings are set crosswise on the lower deck; “H” shaped welded members to be used. The transversal steel girder on lower deck also functions as the strut of lower plane bracing. The main truss width is larger than panel length, so the upper and lower plane longitudinal bracing adopt diamond type, and the stiffened chord’s plane bracing adopts “K” shaped type, to avoid small angle between diagonal members of plane bracing. Because of some inclination existing between the adjacent plane bracing, the gusset plate should be bended to adjust it. At the figure center of “米” shaped plane longitudinal bracing, a truss transversal bracing to be set for each two panels of main arch rib, to strengthen space rigidity of arch rib, and reduce the calculated free length of diagonal rod. At the zone of stiffened leg, one truss transversal bracing to be set for each panel.

3.6 Pre-camber

The pre-camber of the main truss camber is set and adjusted in accordance with the reverse deflection curve value due to dead load plus static live load. From the analysis result, pre-camber is not necessary for the end span, the pre-camber for middle span to be set as following: at the panel joints of stiffened legs, the transversal truss top should be heightened; at the tie zone, transversal truss to be heightened, or suspension rod to be shortened, or adjust centerline of steel members.

4. STRUCTURAL STATIC AND DYNAMIC ANALYSIS

4.1 Static Analysis

The structural plane analysis is carried out with SCDS 2004 developed by BRDI. The analysis model is made only for main truss, taking account of members' rigidity. Table 1 lists the main analysis results.

Table 1 indicates:

- in the double levels of ties, the lower tie plays dominating role, the upper tie force is less than 30% of total tie force;
- under static live load, the deflection-span ratio (1/1730) at the span mid is far less than the permitted value (1/750) in the Code. So we can make a conclusion that the steel truss arch bridge normally has the bigger vertical rigidity, the structural rigidity is not the vital factor in the structural design.

Max. force of members		Tie force		
Tension force	Compressive force	Upper tie	Lower tie	Assistant cable
kN	kN	kN	kN	kN
57138	88398	28209	56991	20000

Bearing force (one truss)		Max. deflection value under static live load			
Side support	Middle support	Deflection on end span (absolute value)		Deflection on middle span (absolute value)	
kN	kN	cm	/L _p	cm	/L _p
9739	145000	16.6	1/1145	31.9	1/1730

Table 1: Structural plane static analysis results

4.2 Stability Analysis

The structural static stability analysis is carried out by space finite element method, by means of software ANSYS. The calculation model simulates the space position, rigidity, and mass of the structural members, the model's border condition to be simulated as actual

support system after bridge completion. The structural static stability analysis results show that the stability safe coefficient is 6.8 in bridge completion phase, meeting the requirements in standards.

4.3 Dynamic Analysis

The structural dynamic analysis adopts the same model as static stability analysis; see Table 2 for main analysis results of the completed bridge.

NO .	Vibration mode	Self-vibration frequency (HZ)	Self-vibration circle frequency (rad/s)
1	Transversal bending of truss, arch	0.1978	1.2428
2	Longitudinal vibration + arch vertical bending	0.2756	1.7316
Contortion frequency ratio $\varepsilon = f_{11}/f_2 = 2.42$			

Table 2: Dynamic characteristics

5. ANTI-CORROSION COATING

The anti-corrosion coating for steel truss conforms to the coating system in Code *The Protection coating for steel railway bridge* (TB/T 1527-2004). And the paint class, painting layer, and dry film thickness in the coating system has been adjusted. See Table 3 for coating system of the steel truss.

Coating No.	Coating item	Min. thickness for total dry film
1	Zinc Rich Epoxy	2×40μm
2	Epoxy MIO	2×40μm
3	Polysiloxane (for chord, tie) Acrylic Aliphatic Polyurethane	2×35μm

Table 3: Anti-corrosion coating for steel truss

6. TRUSS INSTALLATION

The end span should be installed by cantilever method, on trestles and temporary piers. First, two panels of steel truss to be installed on the trestles by means of tower crane beside end pier; next, the erection gantry to be assembled on the upper chord of steel truss; then the erection gantry install the steel trusses in sequence with assistance of temporary piers from end pier to mid pier, by cantilever method. While installing steel truss, some balanced

weight should be used on the end span to make sure that the stability coefficient is larger than 1.3.

The steel truss of mid span will be installed by symmetric full cantilever method with the assistance of sling pylon, and closed at mid-span. The steel truss will be installed first, and then the arch rib truss and suspension robs installed step by step until the mid-span is closed. The sling pylon is 100m high, having two levels of cable; the anchor points of former cable are at 144m and 216m from the pier, back cable anchored at 166m and 178m, the spacing between anchor points on the pylon is 2m. While installing middle span, weight should be forced on the 48m region of end span to make the safe coefficient larger than 1.3. The lower chord of arch rib truss should be closed prior to the upper chord.

After arch truss closed, the temporary tie should be installed and stressed, and then the sling cables and sling pylon should be removed; erection gantry goes backward, the deck crane walks on the upper deck to install ties and upper crossbeams in sequence until mid span is closed. The upper tie should be closed prior to the lower tie; the provisional ties should be removed after while. Then the deck crane goes backward from mid-span to install crossbeam, plane bracing, and longitudinal girder of lower deck, and install upper and lower steel bridge deck. To eliminate the effect of common-action of orthotropic steel plate and main truss, some temporary connection between steel plate and crossbeam will be made; the permanent connection should not be done until all members are installed completely. The assistant cables are installed and stressed after all bridge members completed. After bridge finishing, auxiliary facilities and pavement completed, the assistant cables and suspension rob force will be adjusted to meet design requirements.

7. CONCLUSION

The steel girder of Chaotianmen Yangtze River Bridge was begun to install in August, 2006, the main arch was closed on January 18th, 2008, and the tie-bar was closed on May 18th, 2008. Now, this bridge project has entered the after-installation stage, and the whole bridge will be completed by the end of 2008. Chaotianmen Yangtze River Bridge will be the longest arch bridge in the world. Nowadays, there are more and more application of steel tied arch truss bridges in China; the design and construction of Chaotianmen Yangtze River Bridge can give valuable experience for bridges of the same type.



Figure 3: Photo of Chaotianmen Yangtze River Bridge

