The construction technology of Chongqing Chaotianmen Bridge

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ABSTRACT: Chongqing Chaotianmen Yangtze River Bridge, with a main span of 552m, was completed and opened to traffic in May, 2009 in the bridge capital of China, Chongqing City. In this paper, the bridge is introduced, focus on the structural system and construction features of the bridge, key technologies in steel beam erection, non-stress closure measures of the main arch and bowstrings, welding of the bridge panels, discovery and treatment of temperature difference in panel and truss structures, structure analysis and procedure control in construction, etc.

1 INTRODUCTION

Chongqing Chaotianmen locates at the crossing of the Yangtze River and the Jialing River, which has been the gate of waterway for Chongqing since past time. In the ancient time, the officials in Chongqing received the decree of the emperor here. Chaotianmen has been the landmark of Chongqing，China.

The Chaotianmen River Bridge locates 1km downstream of Chongqing Chaotianmen Square, crossing the Yangtze River, and it is a large bridge connecting the north bank and south bank. The main bridge is a half-through continuous steel truss arch bridge, providing double decks for highway and railway. The upper bridge deck is two-way six-lane and sidewalks with a total width of 36m; while the lower bridge deck accommodate the two-lane urban rail lines at the middle, as well as reserve 7m wide room on each side for the vehicle.

The bridge with a main span of 552 meters is the longest span one in the world, 2 meters longer than that of Shanghai Lupu Bridge. The Chaotianmen River Bridge is a perfect combination of the bridge engineering and architecture, and become a new landmark of Chongqing famous as a bridge city. This bridge was constructed in 2005 and was completed in 2009. Fig. 1 shows the Chongqing Chaotianmen Bridge at night.

Figure 1 : Night view of Chongqing Chaotianmen Bridge

2 DESCRIPTION OF CHONGQING CHAOTIANMEN BRIDGE

Chongqing Chaotianmen Bridge is a three-span continuous bridge system. The main span is 552m with the truss arch loading characteristic at the middle of 488m. The distance between the top of the arch and the support at the central span is 142m as shown in Fig.2.

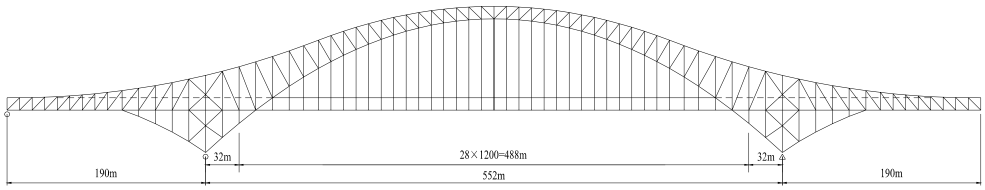

Figure 2 : Structure System of Chongqing Chaotianmen Bridge

The force in the main truss rods on the steel truss girder (arch) has the significant difference during the construction and service state. In order to make sure of the structure safety, the high strength steel was used to reduce the cross section of the truss rod, as well as the different cross section (changed height, 2 different width) of the truss rod was used based on the loading.The assemble nodes were used except the nodes at the middle support to reduce the fabrication difficulty and the cost.The double-level truss balance along with the bridge thrust was used at the main span to simplify the load transfer between the truss components. The double-level truss consisted of steel plates. The change of the part level theory linear system was used to resolve the secondary stress in the truss. The pin support (14500t, largest pin support in the world) was used at the main truss nodes. Orthotropic steel bridge decks were used at the upper and the lower bridge level, while the parts of the deck were connected by truss.

3 GENERAL CONSTRUCTION PLAN

3.1 Determination of the Installation Starting Point for Superstructure at Main Bridge

There were 2 options for the installation starting points at the main steel truss bridge superstructure. One was the side support as the starting point, using the fixed-side pier next to the rack installation of the lifting equipment at the 1 # and # 2 truss section (24m in length), as the installation and commission work platform girder cranes; the remaining components were used full-bridge girder cantilever crane installation. The features were as following: the torque at the side pier next to the tower crane was small (900t.m), 1 crane was needed to be installed at the side and the middle arch cantilever, three temporary piers supporting need to be installed at the side span, it was difficulty to position the middle support precisely and the installation period was long; the other one was the middle support as the starting point, at least one truss section (16m) was installed as the girder installation platform on each side of the middle support. The features were as following: the installation period was short, it was easy to position precisely, 2 temporary piers for the side span cantilever installation, the main pier was needed to fix the initial installation truss section temporarily, the torque at the side pier next to the tower crane was large (2800t.m), when the mid-span truss arch was installed to a certain cantilever length, it could be installed further until waiting the completion of the side span installation as well as taking measurements to prevent overturning, 1 crane was needed at both side span and middle span. After the comparison, if the side point was chosen as the starting point, the construction process was easier, the requirements for the installation equipment was lower, the project safety and technical economic factors were better. According to the project background, the side point was chosen as the installation point.

3.2 Middle span Closure Mode Selection

According to the design requirement, the truss arch and the steel truss at mid-span should be closure without stress. There were 2 options for the truss arch and the steel truss at mid-span closure without stress.

One is the mid-span truss arch and the upper and the lower steel tie bar was cantilever installed simultaneously to the middle span and was closure (Fig.3). The features were as following: ①No temporary tie bar, truss arch and steel tie bar closure simultaneously, transfer the system from the cantilever to the truss arch quickly, the construction transformation number was small, and the construction period was short; ②After the closure of the truss arch at the mid-span, the steel truss at mid-span was in the state of negative deviation, and the closure mode of the steel truss was simple; ③The self-weight of the cantilever end at the middle span was large, the maximum overturning moment was 570000t/m per truss during the installation, the loading of 3000t per truss need to be added the side support to prevent overturning. The weight of the bridge was 12000t and it was difficult to install; ④There were many components controlled by the construction condition. 3 pairs of buckle cable control main truss internal force need to be set up during the construction. It was difficult to control; ⑤The displacement of the cantilever end under the self-weight was large before the closure of the truss arch at mid-span. It was difficulty to control the closure; ⑥The wind resistance and the overall stability of the cantilever were not good. There was higher risk of construction.

The other one is the installation of the cantilever to the mid-span, after the closure of the truss arch, the temporary truss was installed at the suitable location. The steel truss was closed at middle span after the truss arch system was formed (Fig.4). The features were as following: 1. The self-weight of the cantilever end at the middle span was small, the maximum overturning moment was 418000t/m per truss during the installation. The loading close to the side support was 2200t per truss. The weight of the bridge was 8800t and it was easy to load; 2. There were fewer components controlled by the construction condition. The economy of the main structure was good. 2 pairs of buckle cable control main truss internal force needs to be set up during the construction; 3.The displacement of the cantilever end under the self-weight was small before the closure of the truss arch at mid-span. It was relatively easy to control the closure; 4. The wind resistance and the overall stability of the cantilever were good. There was lower risk of construction; 5. The temporary truss was required at the appropriate location of the truss arch lower chord at middle span; 6. Temporary truss was required to transfer the system from the cantilever to the truss arch after the closure of the truss arch. The construction transformation number was large. The state of the steel truss closure at mid-span was controlled entirely by the theoretical analysis of the temporary truss Control. There might be the large positive deviation at the mid-span when the steel truss was closed. It was difficulty to control the closure and the construction period was long.

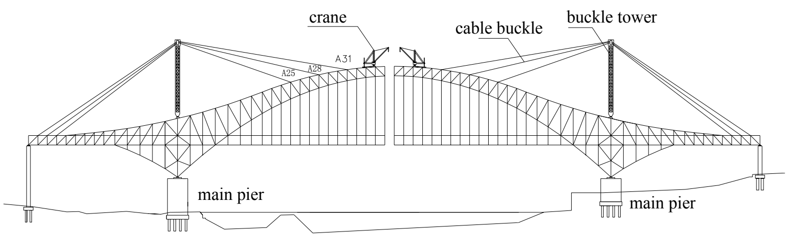

Figure 3 : Layout for Arch and Steel Truss Closure at Mid-Span Simultaneously

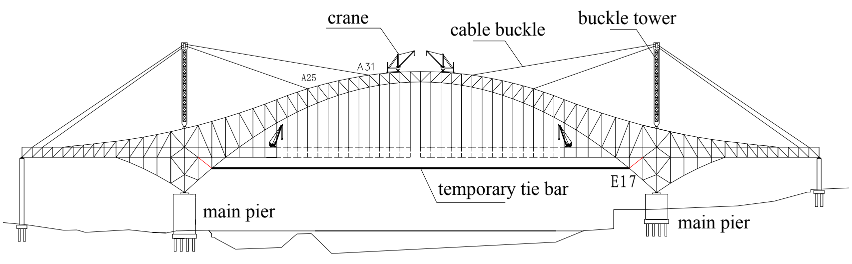

Figure 4 : Layout for Arch and Steel Truss Closure at Mid-Span Asynchronous

According to the project background, considering reliability and economy of the construction as well as reducing the construction risk, the installation of the cantilever to the mid-span of chosen. After the closure of the truss arch, the temporary truss was setup at the suitable location at middle span to form truss arch system. At last, the steel truss was closure at the middle span.

3.3 General Construction Plan

(1) Steel truss components manufactured by non-stress length, shipped to the field site after assembly, installed as the lifting element after pre-assembled with the front node plate;
(2) 3 temporary pier supports from both side supports were used to cantilever installation to the mid-span to form truss arch;
(3) The 3 stages of the large cantilever installations by crane with temporary pressure weight and cable-stayed suspender system were used to form steel truss beam at middle span;
(4) The side span deck and the truss arch were installed simultaneously. After the transformation of the main structure loading system with closure of the steel truss, the bridge deck at the middle span was installed by crane.
The general construction plan was shown in Fig.5.

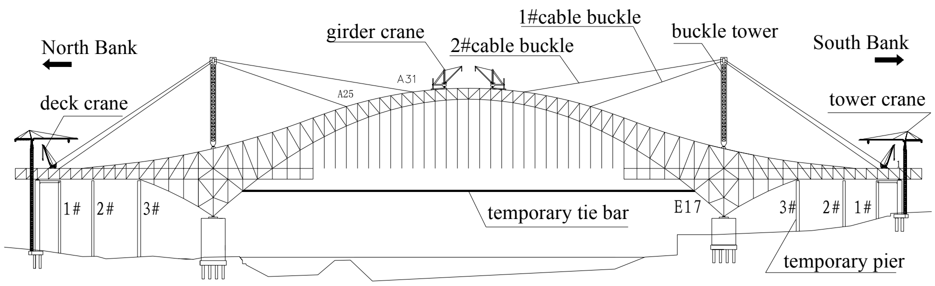

Figure 5 : General Construction Plan

4 CONSTRUCTION CONTROL

4.1 Control Goals

The structure integrity stability during the construction process and the structure stress were controlled in the safety range to realize the closure, which made sure the bridge internal forces and the structure geometric meet the design requirements.

4.2 Main Control Contents

The main contents were as following: the structure analysis and calculation of the bridge construction process and the completion of the bridge; the confirmation and the adjustment recommendation of the bridge construction plan, process, and the completion of the bridge; the control of the side span steel truss cantilever installation process; the control of the side span steel truss beam formation; the control of the middle support installation process; the control of the inclined cable-stayed buckle implement and the loading at the side span; the control of the truss arch closure (first system transformation); the control of the steel truss arch span adjustment and the temporary truss installation; the control of the main span steel truss installation; the control of the bridge steel truss closure (second system transformation); the control of the flexible truss installation; the adjustment of the suspender; the control of the bridge construction, and the adjustment of the bridge deck.

4.3 Structure Simulation Analysis of Construction Control

Structural simulation analysis control was the key process of the reliability of the bridge accident control. Based on the combination of the reverse disassemble-forward assemble analysis method, global model was used (Fig.6). The structure analysis construction process was divided into 123 periods for the structure geometry, stress, and stability, which provided the theoretical prediction control for the construction.

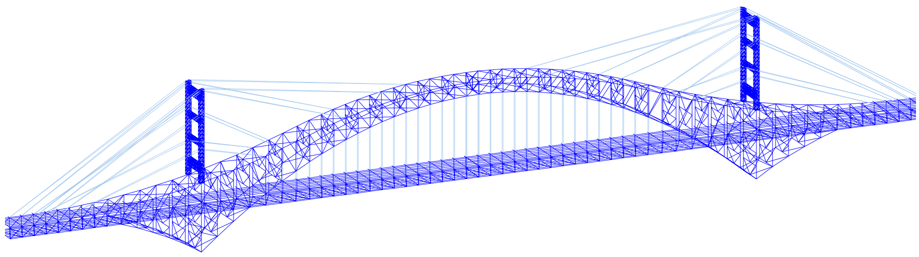

Figure 6 : Simulation Analysis of the Global Construction Control Model

During the simulation analysis of the control, tangent assembly instead of the traditional broken line assembly was used, which realized the simulation analysis of the control according to the actual construction and installation location for the bridge construction process , and make sure the authenticity of the geometric conditions and the internal forces. The closure of the main arch and the rigid truss was ensured.

4.4 Main Control Strategy

(1) Multi-factor, variable parameters, real-time target variable weight matrix method were used to carry out the calculation of the target parameter adjustment required by construction control, which increased the calculation efficiency, and optimized the construction adjustment procedure;
(2) Tangent assembly calculation instead of the traditional broken line assembly calculation was used, which realized the spatial simulation control analysis of the whole bridge construction process;
(3) The combination of the construction prediction and the parameter adjustment within the tolerance was established;
(4) The configuration of the steel beam structure construction was mainly ensured by the factory quality control. The spatial configuration of the field site installation was ensured by the control coincidence rate of the bolt hole and the impact of sunlight partial adjustment;
(5) With the help the lifting jack to change the elevation of the side support, which can change the configuration. The loading weight at side span was used to make sure the anti-overturning stability factor of the cantilever end as 1.3, while the flexibility of the weight (Fig.5) was used to improve the local structure force during the construction.

5 TEMPORARY PIER SETUP AT SIDE SPAN, INSTALLATION OF STEEL GIRDER, AND SUPPORT RELEASE

5.1 Temporary Pier Setup

3 temporary piers were setup as the supplementary support when the steel girder was installed at side-span shown in Fig.7 (the side pier located closed to the crane). The temporary pier was Q235 Φ 800×16mm Steel tube lattice column. The distribution beam at the top was the welded box girder with simply supported boundary condition. The temporary pier was designed the reaction force based on that the supported steel truss girder was simply supported cantilever beam with the maximum arm.

Figure 7 : Cross-Section View of the Temporary Pier at North Side Span

5.2 Installation of the Steel Girder

In order to install the steel girder at the side span, in addition to the 3 temporary piers was setup as the secondary support; the temporary nodes were setup outside the side span for the temporary weight. The falsework was setup between the 1＃ temporary pier and the side pier. 1000t.m crane was used on the 1#、2# truss node on the falsework. As the installation and adjustment girder crane platform, the girder crane cantilever assembly was used to install the remaining internodes at side span. In order to meet the requirement of the closure without stress arch mid-span as well as the location of the north middle support precisely, the side support was moved down 2.3m before the installation of the truss girder at side span. The installation starting point at south side span moved to the mid-span 65cm. The initial installation tilt angle was 1.138°. The pre-control elevation was shown in Table 1.

Table 1 : Installation Pre-Control Elevation for Steel Girder at Side Span

Design elevation for side support	Side support settlement	Construction elevation for side pier	Temporary support elevation for side support
241.357m	-2.3m	236.307m	239.057m
1＃temporary pier elevation	2＃temporary pier elevation	3＃temporary pier elevation	Middle support elevation
239.534m	240.107m	240.704m	200.707m

From the final results, because of the accuracy initial installation position of the side-span steel girder, the closure without stress was obtained without pushing the P8 pier support.The theoretical middle span was 552.824m and the field middle span was 552.809m. The control accuracy was very high.

5.3 Steel Girder Support Release

The release of the temporary pier means the transformation of the structure system during the construction.

(1) Self-Release. During the installation of the steel truss cantilever, the self-weight of the cantilever steel girder was used to self-release the steel girder at side span and the temporary pier. According to the control analysis, the 1 #, 2 # temporary pier was self-release during the installation of the No. 26 internode at middle span. # 3 temporary pier was self-release after the installation of the No. 25 internode at middle span;

(2) In order to adjust the geometry condition on time during the installation of the steel girder, which help to realize the closure of the steel truss girder without stress at the main span. Meanwhile, it reduced the secondary stress of the hypostatic system caused by the temperature. Ensuring the safety of the structure, the 2 #, 3 # temporary pier were advanced released. The 2 #

temporary pier was released during the installation of the No. 14 internode; while the 5 # temporary pier was released during the installation of the No. 22 internode.

6 INSTALLATION AND CLOSURE OF THE INCLINED CABLE-STAYED BUCKLE AT MIDDLE SPAN ARCH

6.1 Inclined Cable-Stayed Buckle System Setup

In order to make sure the structure safety of the middle span cantilever arch during the construction, the configuration of the arch, and the requirement of the zero stress closure, the inclined cable-stayed buckle was installed (Fig.5). For the small span bridge, a pair of high-strength steel wire was used as the cable buckle. Through the research, two pairs of steel cable-stayed buckle were used in the bridge. $4\times 37\Phi 15.24$ steel cables were used as the inside and outside cable at side span per truss; while, $2\times 61\Phi 15.24$ steel cable was used as the inside and outside cable at main span per truss.

The cable-stayed buckle system consists of buckle tower, sling, anchor, steel anchor box, wind cable, and so on. The buckle cable force met the design requirement of the main structure internal stress during the all stages of the construction. The safety factor was greater than 2.0.

The single-cable single-tension construction process was used to the steel cable buckle. It was controlled by the cable length and the cable force, while the cable force was the main factor. The single strand synchronous symmetrical one-time tension was reached. The single strand post-tension and the adjustment of the cable force were avoided, which helped the safety installation of the middle span steel arch and the closure without stress.

6.2 Closure of the Main Span Arch

By changing the relative altitude of the side support and the middle support, at the three-span continuous structure, the zero stress (moment, shear and the relative angle are zero) closure at the mid-span was achieved.

To achieve the zero stress closure of the arch, the pre-control by the pre-construction control analysis was conduct, then the error caused by the three dimensional displacement of the south north support and the temperature change at the south middle support was adjusted. The zero stress closure at the mid-span of the arch was obtained by compensating the closure displacement with the pre-displacement approach. The closure procedure was as following: down truss, up truss, diagonal truss, and horizontal truss. The temperature closure was used for the down truss. The necessary enforcement measurement closure was used for the up truss. The temperature closure was used for the diagonal truss and the horizontal truss.

Due to the pre-control of the structure installation and the adjustment during the construction, the enforcement was not used during the closure of the main arch at the mid-span. The zero stress closure was obtained.

Installation and Closure of Middle Span Arch was shown in Fig.8.

Figure 8 : Installation and Closure of Middle Span Arch

The error at the closure was shown in Table 2.

Table 2 : Closure Error at Main Span Arch and Rigid Truss

Direction	Main Arch		Rigid Truss	
	Allowance Error (mm)	Actual Error (mm)	Allowance Error (mm)	Actual Error (mm)
Longitudinal	30	9	30	4
Transverse	20	2	20	7
Vertical	20	3	20	6

7 INSTALLATION OF TEMPORARY TRUSS AND CLOSURE OF RIGID TRUSS AT MAIN SPAN

7.1 Installation of Temporary Truss Cable

In order to realize the stability and the safety of the rigid truss during the installation, as well as to help the zero stress closure of the rigid truss, the temporary truss cables were installed after the main arch to balance the horizontal thrust at the arch foot as shown in Fig. 5.

Φ15.24 high-strength low-relaxation steel wire was used as the temporary truss cable. The ultimate tension strength was 1860Mpa. There were 360 wires divided into 8 sets per truss.The design control tension was 45000KN per truss. The safety factor was greater than 2.0.

7.2 Closure of Rigid Truss

The pre-control of the temporary truss tension determined by the pre-construction theoretical analysis was conducted, then the rigid truss zero stress closure was realized by the adjustment of the temporary truss cable force and the displacement of the south middle support.

The closure procedure was as following: hoisting closure of the down truss, keep the cantilever, hoisting closure of the up truss, keep the cantilever, install the steel truss, connect the up truss and the flexible, install bridge deck, install longitudinal beam and the down diaphragm, up diaphragm, check the bias of the rigid truss closure, adjust the rotation of the closure by moving the side support, adjust the longitudinal closure bias by tension the temporary truss, closure the up truss, lift the side support, closure the down truss and the light rail longitudinal beam.

The zero stress closure of the rigid truss was realized finally. The closure error was shown in Table 2.

8 CONTROL MEASUREMENT OF THE BRIDGE DECK WELDING AND FIND AND DISPOSAL OF PLATE GIRDER TEMPERATURE DIFFERENCE

8.1 Control Measurement of the Bridge Deck Welding

After the installation of the bridge deck, by controlling the outside cable tension force of the down truss, the axial force of the up and down steel truss at middle span was adjusted to the loading condition of the second-stage dead loads after the construction, in which the middle span reached 522.80m; the force in up rigid truss was 23000KN per truss; the force in down rigid truss was 46000KN per truss. Then the welding of the bridge deck as well as the connection of the diaphragm realized the design strategy of the bridge deck did not participate the main structure loading.

8.2 Detection and Treatment of Plate Girder Temperature Difference

To the steel bridge, there is no code has the requirement of the temperature difference between the different components on the same level under the same sunshine condition. The ultimate temperature is used as the temperature difference of the system without considering the effect of the temperature difference on the structure between the different components under the same sunshine condition. During the construction, after the inspection of the temperature on different components on the bridge deck and the main truss, the temperature difference between the bridge deck and the main truss (arch) was found out (temperature difference in upper level was 15℃, (temperature difference in lower level was 6℃). The temperature difference between the plate and the girder is the new technology of the bridge construction. The effect of the temperature difference on the construction can be avoided by welding; however, the effect on the structure loading system needs to be considered after the completion of the bridge.

REFERENCE

Zhongfu Xiang, 2001, Bridge Construction Monitoring Technology, China Communications Press, Beijing.