Construction techniques of the arch ring of Panzhihua Baishagou Bridge

Z. Zhang
Sichuan Road & Bridge Co.,Ltd.,Chengdu, P.R.China

X. Niao and D. Nie
Sichuan Road & Bridge Co.,Ltd.,Chengdu, P.R.China

W. He
South West Jiaotong University, Department of bridge&structure Engineering, Chengdu, P.R.China

B. Pei
Sichuan Road & Bridge Co.,Ltd.,Chengdu, P.R.China

ABSTRACT: Panzhihua Baishagou Bridge is a reinforced concrete arch bridge with the net span of 150m. The cantilever casting method with suspended wagon was first used to construct the arch ring segments in China. The cross section of arch rib adopted the twin-box single cross section with 6m in width and 2.7m in height. The segment of arch springing were cast in place on the scaffolds; ten segments of each half-span were constructed by cantilever casting method; the closed segment on the crown was constructed in the suspended bracket. The maximum length of the segment is 7.79m, and the heaviest segment is about 122t. The key construction techniques were described in this paper, such as the strutting frame method for the cast-in-place segment, truss-type suspended basket and the cantilever casting method, the cable-stayed fastening system for the construction and so on.

1 INTRODUCION

The long span reinforced concrete box arch bridge is one of the feasible and economical type of bridge in mountainous areas, which can preferably adapt to the mountainous area topography. For the reinforced concrete structure has the characteristic of high compressive strength and the arch structure has the good capability to resist earthquake. Comparing with the other bridge types such as the rigid frame bridge and the continuous bridge, the long span reinforced concrete arch bridge has the characters of better endurance, easier maintenance and less cost in the conduction of rock foundation and high foundation bearing capacity.

Constructing the arch ring is the most important and difficult technology for building the reinforced concrete box arch bridge.When the construction field is limited in mountainous areas, cantilever casting method will become a feasible choice. Although the Chinese construction technique of arch bridge has reached the international advanced level, technology of arch ring cantilever casting construction is almost a blank. In the project of the Xichang-Panzhihua Expressway, the suspended basket cantilever casting construction technology for the arch ring was applied successfully for the construction of the Panzhihua Baishagou Bridge. This paper will present the technical scheme, construction technology and construction control about this bridge.

The Baishagou Bridge was relied on the research project named “Research of design and construction technology of the long span reinforced concrete box arch bridges in mountainous areas”, which was a project of TCSTWC(Traffic Construction Science and Technology in West China). Suspended basket cantilever casting construction technology was the first time used in China to build the arch ring. Two separate bridges were designed to fit the different elevation of roadbed in the same site. The span arrangement of this bridge is 4×14.2m (approach bridge)+150m (reinforced concrete box arch bridge)+3×14.2m(approach bridge), see Fig.1.

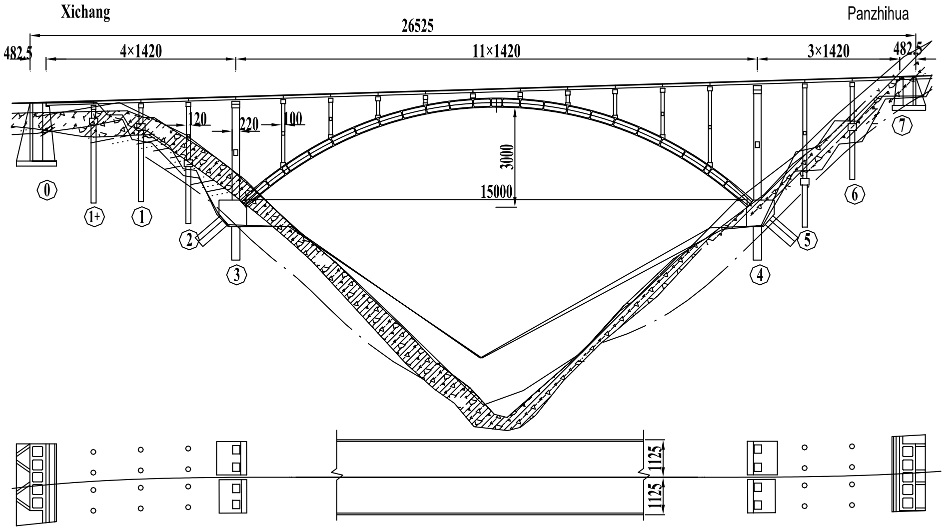

Figure 1: Layout of the bridge

The main design characters of such bridge were list in the Table 1.

Table 1: Design parameters of the arch ring

Design Parameters	Design Value
Net span(L)	150m
Net raise(f)	30m
f/L	1/5
Catenary coefficient (m)	1.988
Width of the section	6m
Height of the section	2.7m
Thickness of the top and bottom flange	0.6m(spring)~0.25m(crown)
Thickness of the outer webs	0.5m(spring)~0.3m(crown)
Thickness of the middle web	0.5m(spring)~0.2m(crown)
Thickness of the diaphragms under the column	0.35m
Thickness of the normal diaphragms	0.25m
Number of the cantilever casting segments	20
Length of the closed segment	2m

2 CONSTRUCION SCHEME

In the Panzhihua Baishagou Bridge, except the footing segments of arch ring were constructed by cast-in-site method with scaffolds, the other segments were constructed by suspended basket cantilever casting technology. The closure segment is cast on the suspended bracket after the stiffening frameworks had been installed. During the segment construction, the segments from no.1 to no.4 were fastened by cables which were anchored directly to the head beam of the transition pier. The unbalanced horizontal force occurred in the bead beam of the transition pier were balanced by the 1^{st} anchor-cable anchored at the head beam of the transition pier. The segments from no.5 to no.11 were fastened by cables which anchored at the temporary pylon. The unbalanced horizontal force occurred in the pylon was balanced by the 2^{nd} anchor-cable, see Fig.2.

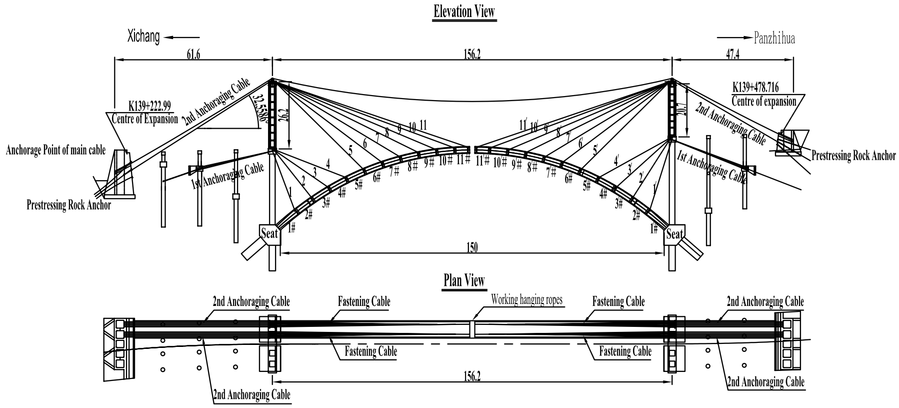

Figure 2: General arrangement of construction

2.1 *Scaffolding scheme for cast-in-situ segment*

The scaffolds for footing segments could be set up by standardized equipments such as the fabricated universal bars, the triangular truss and the Bailey truss. Scaffolds also could be made by worksite prefabricated materials such as steel tubes or shaped bars. In this bridge, to reduce the non-elasticity deformation, spire welded steel tubes with the size of φ 720×10mm were used to erect the scaffolds by welding them together. On the top of the tubes, profiled bars were placed longitudinally. By the support of the tubes and the corbels pre-buried in the skewback, the longitudinal beam worked as two span continuous beams. Considering the factors of the horizontal thrust caused by the slope of the spring segments, shaped steel bars were pre-buried into the arch seats; scaffolds were optimized and welded to the shaped bars, so as to keep the stability. Transverse trough bars were placed on the longitudinal beams, modulation blocks were placed on both the transverse and the longitudinal beams to suit the arch curve and to guarantee the shape of the bottom formwork plates.

2.2 *Suspended basket*

The suspended basket is the main load bearing structure in the segment construction. The suspended baskets used in bridges were classified into different types by their structure forms, appearance and support forms. Before the Panzhihua Baishagou Bridge was constructed, the hanging baskets used in the beam bridges and the cable stayed bridges worked in the ways of horizontal cantilever casting and did not employ in arch bridges in China. The structure of the suspended basket was designed as rear-support and lateral triangular truss with consideration of narrow arch ring, incline of segments and variety incline angle (See Fig.3). The feature of such equipment was well combined the load bearing truss system with the bottom basket supporting system. The hanging girder worked not only as the main load bearing system but also as the travelling system. The reaction acts on the bottom of the cast segment through the cross beams in rump of the triangular truss.

This suspended basket includes main truss system, rein thrust system, supporting reaction system, traveling system, formwork system, working hanging basket, safety protection system, etc. The main design parameters of the suspended basket were shown in Table 2.

Table 2: Design parameters of the suspended basket

Design Parameters	Design Value	Units
Total length of the truss	16.8	m
Total height of the basket	4.4	m
Self weight of the truss	42.5	ton
Design vertical force limits in horizontal state	220	ton

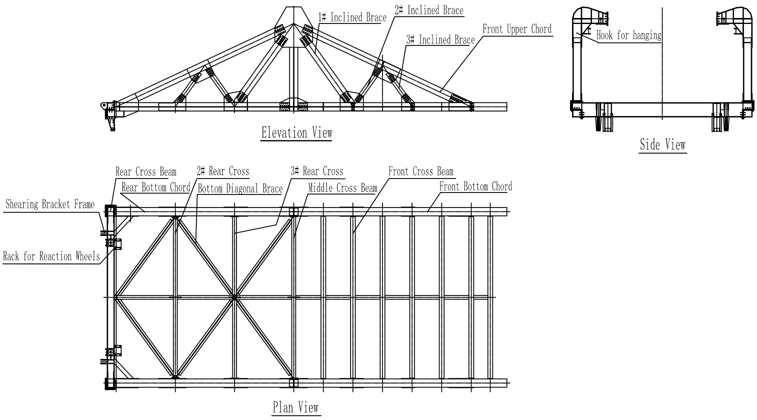

Figure 3: the suspended basket for cantilever casting

2.3 Cable tower

Several types of cable tower were considered such as the universal bars pylon, the concrete-filled steel tube pylon, the hollowed steel tube pylon. The displacement on the top of this cable tower was very strict during construction, therefore the universal bars pylon was denied firstly because the nonlinear deformations due to the bolt holes can not be computed accurately, which could introduce many uncertainties. The concrete-filled steel tube pylon was excluded secondly. It's known that the CFST structure could work reliably, but the pylon should be supported at the top beam of the pier in this case, the heavier weight would endanger the bearing capacity of the top beam. If considering that the pylon for fastening cable is a temporary structure and should be removed after serving, the re-use value of the CFST structure was poor. The hollowed steel tube pylon was chosen finally.

To erect one pylon, six trestle tubes were used by the arrangement of two columns and three rows. The main tubes were spire welded tubes with the size of φ 720×10mm. Depending on the height of the tower and the capacity of the hoist, each column was divided into three segments and jointed each other by flange connections. The longitudinal centre distance of the main tubes was 2.2m, two main tubes were connected by welded φ 325×7mm tubes to form a whole component for lifting. By such method, the better fix quality could be achieved. The transverse distance between the two main tubes was 3m and the distance between the inner main tubes to the outer tubes was 6m. Trough bars were welded the tubes to connection them crossly.

The pylon was supported at the transverse slide way on the top beam of the pier, fixed by the nuts to the pre-buried reinforcements in the beam. After one separated bridge was completed, the reinforcements would be chopped up, and the pylon would be moved to the other separated bridge.

2.4 Anchorage system

The anchorage system in the construction was drafted by the design institute. The two 1^{st} anchor-cables were anchored at the distribution beams on Pier 1(Xichang Side) and Pier 6(Panzhihua Side), the two 2^{nd} anchor-cables were anchored at the distribution beams on Abutment 0 and Abutment 7, see Fig.2. The dental plates for anchoring were adjusted according to the arrangement of the anchor blocks on the pylon, The cable strands were parallel each other and the distance between the centre of the anchor plates were 50cm. The anchorage for the hanging system and the anchorage for the fastening cables were banded together. The φ 800×10mm steel tubes were buried between the front wall and the back wall of the abutment, functioned as the anchoring pass for the main strands which were anchored on the cross beam located on the back wall.

2.5 Cable-stayed fastening and anchoring system

The low relaxation stranded wires were used for both the fastening cables and the anchor cables. The diameter of the strand is 15.24mm, the standard tensile strength (R_y^b) is 1860MPa and the elastic modulus (Ey) is 1.95($^{+0.1}_{-0}$)×10^5MPa. Since the fastening stands had lower stress, the reliability of the strands anchoring became one sticking point for the construction in this bridge. The P shaped anchorages were used for the fixed end of the strands. The strands were locked on the special anchorage device by the whorled ring. After putting the strands with their anchorage heads through the tubes buried in the arch ring, the anchor bolts then would be installed so as to make the strands anchor on the steel plate inside the arch. Considering the requirement of cable force adjusting and the demand to remove the cable, the anchorage device for the jacking end should have the functions such as stretching the strand, thrusting the clampingpiece, locking and unlocking, inching adjusting the force, etc. The YM pre-stressing clamp anchoring system which has the excellent capability in low stress was applied in this bridge for the purpose of keep the construction safety. Such system was developed by our company and had been applied in the project of Wushan Yangtze Bridge successfully(Zhang 2003 and Zhang 2006).

3 CONSTRUCTION TECHNOLOGY

3.1 Construction technology and procedure

The construction processes of arch ring are as follows:

(1)Erect the scaffolds for the spring segments.
(2)Cast the spring segments and maintain the concrete to reach the required strength.
(3)Install the 1st fastening cable and the 1st anchor-cable; stretch them to the required force.
(4)Remove the scaffolds of the cast-in-site segments.
(5)Install the suspended basket, debug such equipment and prepare for the cantilever casting.
(6) Fasten the segment reinforcements for bottom slab, web and diaphragm.
(7) Install the inner formwork and the side formwork.
(8) Fasten the reinforcements for top slab of the arch ring.
(9) Install the top formwork.
(10) Cast the segment and cure the concrete to reach the required strength.
(11) Install the fastening cable and the anchor-cable, stretch them to the design value, adjust the cable force subtly, and anchor the strands.
(l2)Loose the hanging basket; transfer it forward to the next segment location.
(13)Begin the next segment cycle until all the cantilever segments are finished.
(14)Carry out the work for the closed segment.
(15)Remove the fastening cable and the anchor-cable by the design sequence and the design grade.

The period of every segment construction stage was shown in Table.3 and the total time of one construction cycle is about 288 hours (12 days).

Table 3: Period of one segment construction

No	Item	Time (hour)
1	Move the hanging basket, adjust the bottom shuttering.	18
2	Fasten the reinforcements for bottom slab, web and diaphragm.	48
3	Install the inner formwork.	36
4	Fasten the reinforcements for top deck, install the pre-buried member.	30
5	Install the top formwork	12
6	Cast the concrete of arch ring	12
7	Cure the concrete	96
8	Fasten and anchor the cable, jack and adjust the strands.	36

3.2 Outline of construction technology

The main points of the arch ring construction technology could be described as the following:

(1)To the scaffolds of the footing segment, the bearing capacity of the foundation soil must satisfy the requirement of the design. The stiff connection should be used in the strutting frame to reduce the non-elasticity deformation. The scaffolds must be connected to the arch seat to balance the horizontal thrust caused by the slope of the spring segments.

(2)For the lateral triangular truss type cradle used in this project, the elevation of the bottom formwork should be adjusted by screwing the rod after the installing of the cradle. The important parts should be controlled carefully, such as the support point of the hanging hook, the reaction support point of the rear cross beam, the shear-resistance block of the basket, etc. The travel of the suspended basket would be carried out by the thrusting of the jack installed at the rear beam.

(3) Since the arch axis was catenary, the cambers of the form were different for each segment. The straight segments were used to fit the curve alignment. Each segment of the formwork was about 1.2m long. The adjusting screw rods were set at the formwork junctions to adjust the elevation.

(4)The sequence of fastening the reinforcements should be taken care of. The mechanical connection should be chosen to connect of the longitudinal main bars. The stiff frames should be erected to support the heavy top reinforcements. The cutting of main reinforcement should be avoided as much as we can. Strengthening is the cutting has to be done

(5)The concrete should be produced in the mixing station and then carried to the bridge site by the trucks. The pump method should be chosen to pour the concrete into the formwork. The slump of 16~20cm and the initial setting time of 8 hours were chosen to insure the quality of the concrete.

(6)Since the arch ring segments were inclined, the inner formworks were fully closed and deck formworks were designed as compressed mode. Such formwork system is hard for pouring concrete. For the convenience of pouring and agitating the concrete, holes were opened with the 1m spacing longitudinally on the webs and corresponding forms

(7)The cables for fastening and anchoring were prepared as the ordered length on the ground. The anchor ring and the P shaped anchorage were installed firstly. The working rope was used to lift fastening and anchoring cables, and put the anchor ring of the fixed end into the buried tube and installed the anchor ring. Then lift the jacking end to the anchoring point at the pylon. Finally, drag the jacking end to pass through bearing plate of the anchor with pulleys, then install the anchorage device, the jack, the reaction frame and the lifting jack.

(8)The strands of one cable were jacked singly to the initial tension by the 240kN jack. Tensions in each strand should be adjusted to a uniformity level. Then, the cable should be gradually stretched according to the control instruction. When stretching, keep the balance between the up stream cable and the down stream cable, as well as the balance between the fastening cable and the anchor-cable.

(9)The special low stress clamping piece anchoring system was employed for the tensioning end, which could achieve fine tuning.

4 CONSTRUCTION CONTROL

The construction control work was carried out strictly in the cantilever construction to achieve the following design targets:

(1)Ensure the safety of the structure regarding the force and the deformation at every construction stage

(2)Ensure that the final alignment meets the design requirements and the dead load state is close the design expectation.

4.1 Methods for construction control

(1) Design Parameters Identification

By analysis the errors of measurement data and the theoretical data for the state variables (such as displacement and strain) at the typical construction stage, and according to the influence analysis of the design parameters, the errors of the design parameters would be identified.

(2) Design Parameters Forecasting

The errors occurred in the constructed segments should be used to predict the possible errors happen in the following stages. Appropriate forecast method such as the grey model method might be used.

(3) Optimizing and Regulating

The objectives in the control work are aimed to control the elevation and the bending moment. So the objective function and the constraint conditions in the optimizing and regulating analysis should be considered based on such factors. Through the influence analyzing to the design parameter errors, optimizing methods (such as the weighted minimum squares method and the linear programming method) were used to confirm the framework elevation.

4.2 Items in construction monitoring

For one segment construction cycle, three sub-stages were considered so as to improve the force state of the arch. The sub-stages were: moving the cantilever basket forward and locate the formwork; casting half of the segment concrete, adjust the cable force of the fastening cable and the anchor-cable; casting the rest concrete and adjust the cable force again. In each stage, the main concerned items are listed as the follows:

(1) Survey for deflection

Three survey points were set on the top of the cantilever end for each segment, served as the elevation and the coordinate measure points. For the cast segment, the temporary points were set on the bottom of the ring and the relationship between the temporary and the future fixed point should be measured. The elevations were measured by the precise water level and the coordinates were measured by the electronic total station.

(2)Survey for horizontal displacement on the cable tower

The horizontal displacements were measured by the electronic total station through the measuring points set on the top of the cable tower .

(3)Stress and strain measuring

The strain in the arch section was measured by the string vibration strain gage. The monitoring sections were chosen as the spring section, the quarter span section and the crown section. For the transition pier, the monitoring section was fixed at the section 2 meters away from the bottom.

(4) Temperature measuring

The NTC mode temperature-sensitive resistors were chosen for the concrete temperature monitoring. The transducers were pre-buried in the arch concrete to obtain the thermal field information. To inspect the change of the deformation and the force influenced by the temperature, the different monitoring data should be measured synchronously, such dada include: the ring level, the pylon displacement, the stress and the temperature.

5 MEASURED RESULTS

The left span of the two separated bridges had been closed on January 31, 2007. The final alignment was very smooth. The stress and the deformation in construction stages met the design requirements. The detail results were described in the table 4.

Table 4: Detail results after the construction

Contents	Result described	Values
Ring Stress	Maximal compressive stress during the construction	5.1MPa
	Maximal tension stress in construction	<2.0MPa
Ring alignment	Relative error to the arch level between two symmetrical sections	<33mm
Ring precision	Relative elevation difference between two end segments before closing	4mm
	The elevation error compared to the design value on the vault	10mm
Pylon deform	Maximal horizontal displacement on the top of the pylon	35mm
Cable force	Maximal relative error for the fasten cable force in construction	10%

The segments cantilever construction by suspend basket and the closure segment of the arch ring were shown in Fig.4.

Figure 4.construction process

6 CONCLUSIONS

The cantilever casting construction technology of the arch ring was applied successfully in Panzhihua Baishagou Bridge. With the expressway extending to the outlying mountainous areas, more and more bridges should be built to cross over deep valleys. Considering the construction factors, the arch bridges with box section show more benefit in V shaped valley. When the construction Site is limited, cantilever casting method will become a feasible choice. Through the successful construction of the Panzhihua Baishagou Bridge, the construction technology described in this paper not only enriched the construction method but also filled up the blank of cantilever construction of arch bridge in China.

REFERENCES

1. Zuo-an Zhang.2003. Study on the anchoring system working in low stress station for the fasten cables in Wushan Yangtze Bridge.*Technology of Highway and Transport* 2003(6), p.62-64.
2. Zuo-an Zhang. Shilin Liu. 2006. The Wushan Bridge --worldwide longest-span concrete-filled steel tube arch bridge. *RIA 2006(6)*, p.87-91.