An advanced construction technology for cable-stayed Bailey arch

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ABSTRACT: This paper presents an advanced construction technology for assembling pre-stressed box arch with strips and blocks on a 133m long cable-stayed steel Bailey arch truss for the Wuqiangxi Bridge at Hunan hydropower station in 1989. This project example set a record of completing the construction within 143 days.

1 INNOVATIVE CONSTRUCTION METHOD WITH PUBLIC INTERESTING

1.1 Bridge type

The Wuqiangxi Bridge is an arch bridge (Figure 1), which has the longest span when it was completef in Hunan Province, China. The design of the bridge is 331m long with three unequal spans (70+133+70m) and reinforced concrete box as its navigable span. The other coefficients of the bridge are listed as follows：catenary axis coefficient is 1.167, net arch camber is 1/6, deck width is 13m, design load is that automobile within 20 tons and trailers within 120 tons. The cross section of the main arch ring consists of seven 1.50m-wide-and -1.80m-high box arches, jointed by 0.18m wide cast-in-place concrete to the vertical (slot width of side box is 0.39m). The main arch ring is 12m wide, and on the spandrel structure there are three columns on the top of which are 1.20m wide post-tensioning pre-stressed hollow slabs with 0.80m high hat beam and 6×16m vertical layout. The navigable bridge opening, with 2 φ 9m cylindrical as main pier foundation, is constructed in steel cofferdam, jointed by bearing platform on the top, bottom width of pier shaft 7m.

1.2 Time-limited construction

The construction of this bridge was continued by SINOHYDRO Bureau 8 co., Ltd in 1986. The substructure and foundation construction was completed at the beginning of 1988 and the erection of three segments of U-shaped box rib (25m long, 28t weight) with two opening on both sides (70m) was completed at the end of the same year. The cable crane, 4 φ 60mm wire ropes and lifting capability 30t, was planned to launch the erection of navigable spans at the beginning of 1989. The 133m long box arch was planned to erect by nine units, each 16m long and 34t weight. Since the construction of the dam had already been launched, dam construction and the box arch pre-stressing yard on the both banks of bridge construction interfered with each other, and thousands tons of material and equipment needed to be transported across the river urgently. Therefore, Shangguan Xing, based on the advanced experience of Bailey arch construction in Guangdong Province, who put forward new solution of supporting Bailey arch construction by using the stayed cables, that was to divide 135m long box arch into 30 units and prefabricate at different sites and erected, then assembled them by strips and blocks.

1.3 Characteristics of the new technology

Multiple segments. The section area of each box arch is 0.84m^2 and the weight is 2.2t/m. The 138m-long arch was divided into 30 segments, and then each one is 4.6m long and 11t weight. To deduct the cast-in-place joint width of 0.50m, each box is 4.10m long, 1.8m high, 1.5m wide, and 10t weight. After being loaded by gantry cranes, they can be carried along the road on mountainside to the abutments. On slinging, turn 90 degree to the above of arch construction. Instead of 9 sections, with 30 sections, keep the pre-stressing box arch off bridge location, which solve the problem of lacking room for the central line of bridge location.

Steel Bailey arch construction. In 1969, Bailey steel arch construction has first been put forward when Lanshi Bridge was being built up in Guangdong Province. Its key technology is to install a special component as a joint on top chord first to make the Bailey truss into a polygonal arch, and then fill it with some wooden pads to make the arch smooth enough (refer to Fig.2). It has been proved by practice that such Bailey steel arch construction is safe, convenient, economy and time-saving, which has already been popularized and put into use on nearly ten arch bridges such as the Wudou Bridge (80 m), the Jiaolingbahou Bridge (85 m), the Dapusan River Bridge (3×67m), the Huiyangdong River Bridge (7×75m), the Jiangnan Bridge (6×68), the Yingde Bridge (80 m), the Liuxi River No.1 Bridge (75 m), and the Liuxi River No.2 Bridge with the longest span (90m). However, since the limit height to Bailey truss with 1.5m high, the rigidity and stability can hardly be satisfied unless the arch span is less than 100m.

Function of stayed-cables. The stayed-cables used in the installation of steel arch construction should be dismantled after connection according to the independent force concept of steel arch construction. It is the stayed-cable tension under inadequate control that would result in instability and even collapse of the arch construction. Based on the theory of dead load with no bending moment or deflection proposed by Shangguan xing when he was in charge of construction of Guangdong Jiujiang Bridge, stayed-cable tension and deflection can be under adequate control in the cantilevered assembly process of the cable stayed bridge. Therefore, the theory can also be applied to the cable-stayed Bailey arch construction, which also guarantees stability and safety of 133m-long cable-stayed Bailey steel arch construction.

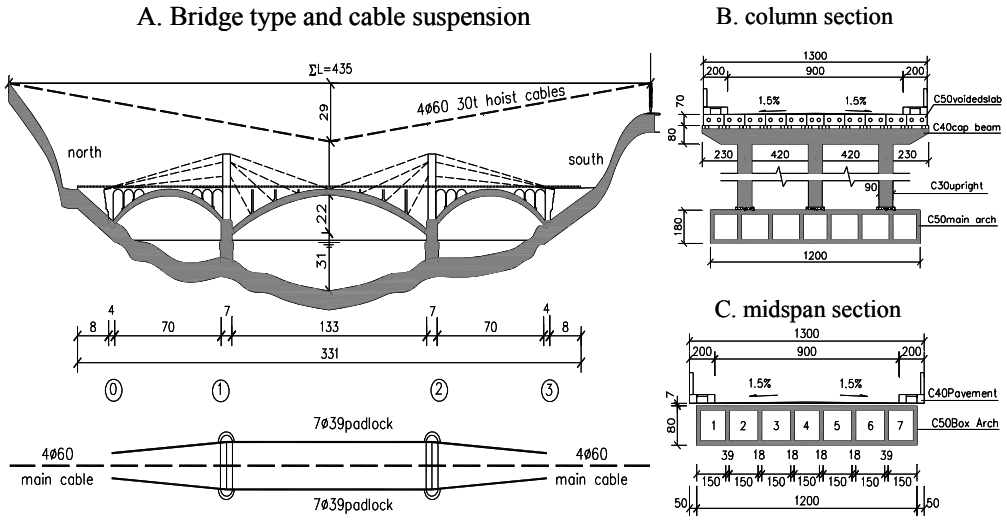


Figure 1 : Construction of Hunan Wuqiangxi Hydropower Station Ruanshui Bridge Figure

2 THE CONSTRUCTION OF THE BAILEY STEEL ARCH

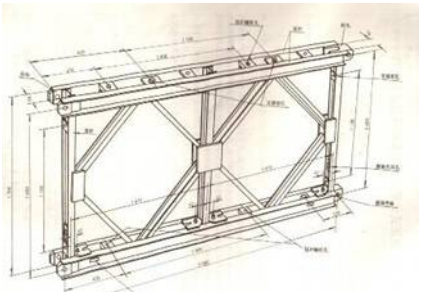
2.1 Bailey truss

The M font truss bridge which was also called Bailey steel bridge was designed by the British engineer Donald in 1939. It was adopt by USA-UK troops as the major component for military

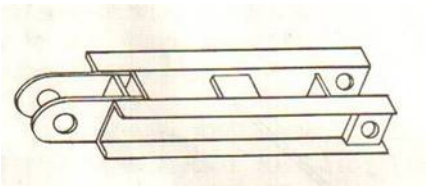
bridge, and was massively used in Europe and Fareast area during the World War Ⅱ. It was in 1960s that this kind of bridge has been put into production in China, named '321' road steel bridge.

Referring to Figure 2, on the top chord, there installs a special component as a joint (length about 11-18m), which leads to the overturn of the head of the two straight truss and makes them into a similar arch of polygonal. There are special ends on the feet of both arch heads, with the upper one connected to Bailey truss and the bottom one to hinge of the abutments, all of which forms an arch with two hinges.

Vertical units are jointed by lateral combination plate and stereoscopic floriculture; nodes on the top chord of the extrados are installed horizontal I-type beams, wedge wooden pads and arch wood, which play an important role in transferring the weight of pre-stressing box arch. Therefore, the elevation of the box arch can be adjusted and fit to the designed elevation of the arch axis line.



(a)



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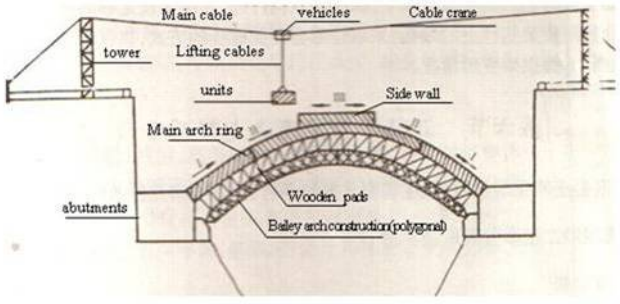


(c)

Figure 2 : Bailey arch construction in Guangdong Province:(a) Military prefabricated "Bailey truss beam, (b) Special component as a joint, (c) Schematic diagram of casting the main arch ring on Bailey arch construction

2.2 133m-long cable-stayed Bailey steel arch (referring to Fig.3)

Transverse layout, totally with four units, installation of two inner units, each unit consists of 5 Bailey (width=1.8m) with spacing of 1.5m,and total width of the arch blocks is 5.1m.These two units are first to be erected, on top of them installed by one piece of No.1 and two pieces of No.2 arch blocks. Installation of two external units, each unit consists of 4 Bailey blocks (width=1.35m), with spacing of 1.95m, and total width of the two outer margins is 11.70m, to be installed by No.3 and No. 4 arch blocks.

Vertical layout, totally with five units, they are divided into three categories according to the fixed position of stayed cable. The first section (OA) consists of two 8.52m and 12.0m long linear Bailey blocks, hung by stayed cable T1, which is called stayed-cable from pier. The second section (AB) and the third one (BC) are hung by stayed cable T2 and T3 on the tower columns of the universal members, which is called stayed-cable from tower. The fourth (CD) and the fifth (DE) section bear excessive axial pressure due to too little level inclination. They are hung by short lifting wires on the main cable, which is called stayed-cable from above.

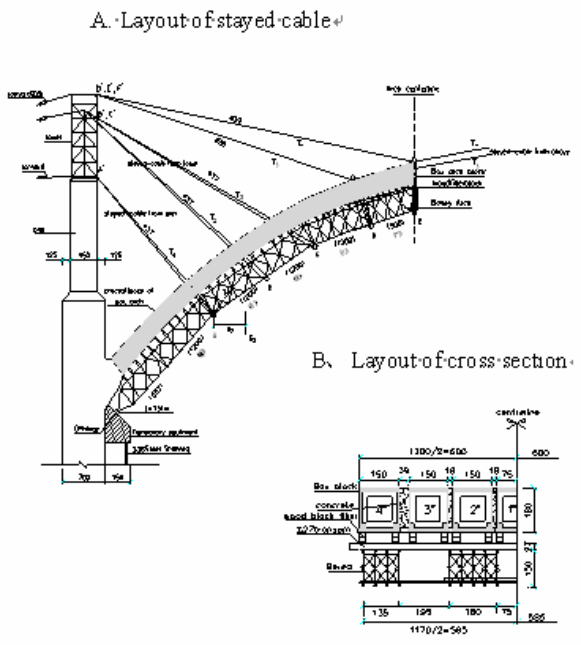


Figure 3 : 133m-long Cable-stayed Bailey Steel Arch Construction

2.3 Stayed cable tension determination

The stayed cable tension is given by the equation;

$$T_i = X_i \times G_i / Z_i \tag{1}$$

Where G_i is the weight of each bailey truss, and Xi and Zi respectively stand for deadweight G_i and the vertical dimension between the force line and the node.

After all the 12 units of the 131m Bailey steel arch construction are connected, the deadweight (about 400t) is borne by Bailey arch. Theoretically, all the stayed cables are free of force; however, they are not to be dismantled at this time. Thus, the stayed-cable arch construction system can be reserved, especially the restriction effect. While the arch construction continues being loaded (install the wooden pads so that the pre-stressing box blocks reach the position), Bailey arch construction will suffer settlement deformation. At this time, stayed-cables can play a significant part in restriction effect, so as to guarantee the stability and safety.

While the pre-stressing No.1 arch box blocks are being loaded, total weight of about 300t is borne by the 10 pieces of Bailey arch blocks in two units. The stayed cable tension T1 to T5 can be calculated based on the formula mentioned above. And it is determined by the equation;

$$T_i = X_i \times P_i / Z_i \tag{2}$$

Where P_i is the weight of each precast block.

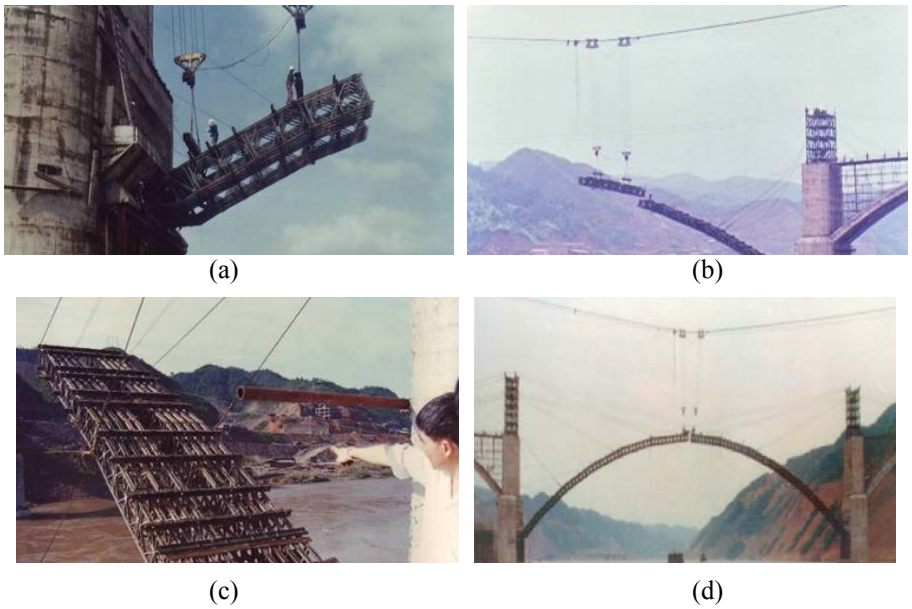
2.4 Measures for safety and stability of the Bailey arch

Bailey is a structure of bolt. The clearance between the bolt and its inner wall can result in deviation of axis line of Bailey arch beam. The larger the span is, the more accumulative deformation it gets. To guarantee the safety, the design should include measures of all kinds. For example, on the completion of connection of No.1 arch box in the middle of the bridge, the two inner units (10 pieces) of Bailey arch construction must be tied with steel wires on point A, B, C, D, E, that is, to utilize the rigidity of the already connected reinforced concrete box arch to support the stability of the Bailey arch construction. On the completion of connection of No.2 arch box, it must be tied to the two inner units (10 pieces) of Bailey arch construction. This

process plays a key role in the construction. Due to asymmetric loading, Bailey arch construction suffered a 0.2m asymmetric deformation once. Thanks to the reinforced concrete arch box, its function of stability has avoided a major accident.

3 ERECTION OF STEEL BAILEY ARCH (REFERRING TO FIG.4)

Installation of 395t weight steel bailey arch has been completed within 29 days, with average speed of 10t/day. Net span of Bailey arch is 131m, the arch length is 136m, total weight is 393t (referring to the Table 1).



(a) (b)

(c) (d)

Figure 4 : Cable-stayed Bailey steel arch construction installation(a) Section A Steel arch construction installation, (b)Section C steel arch construction installation, (c) Midspan steel arch construction hanging, (d) Period before 133m middle-part connection

Table 1 : component form

NO.	Name	Quantity	weight（t）
1	Bailey truss	810	219
2	Bolt	1800	15
3	Support frame	1170	25
4	Bracing-frame bolt	4680	5
5	Special component as a joint	180	5
6	Terminal	36	14
7	Adjustable hinge	36	3
8	No.27 I-type Beam	240	59
9	Chuck	480	1
10	Bolt (matched with NUT)	200	5
11	Shaped steel and steel plate		10
12	Steel rail		26
13	Binding lifting wire		6
14	Total		393

4 INSTALLATION OF THE 133M LONG BOX ARCH

4.1 Construction time of box arch (referring to Fig.5)

Completion of the upper part of the whole 133m long box arch bridge within 143 days has set up a record in China bridge construction. The most important reason is that on entering the site

prefabrication work has been started on the pre-stressing yard out of bridge. prefabrication and erection of the arch have been working in parallel, which brings the assembly with strips and blocks into full play.

4.2 Erection of box blocks is to be carried out from the arch end to top, engineering control principles as follows:

Ever since box blocks installed on the head of stayed cables, Bailey steel arch will suffer settlement deformation under the gravity. Under such circumstances, tighten the stayed cable with the hoister to make sure the elevation of nodes return to the original position. Namely, the function of the stayed cables is to guarantee Bailey steel arch construction free of deformation, which is actually the theory of dead load with no bending moment. In a word, all the measures should be carried out under the principles of fixed elevation of the arch axis line.

4.3 Closure process of the longitudinal box blocks

After erection of the whole arch,adjust the deck with jacks underneath; weld the joint steel; erect the transverse plates (width=0.5m) on the joint; cast the joint concrete from arch foot to arch top and vice versa. In 5days, joint casting work of other box arches can be carried out.

(a)

(b)

(c)

(d)

Figure 5 : 135m box arch construction(a)Erection of No.2 box blocks after No.1 boxes, (b)Erecting box block by cable over the tower top, (c)Erection of No.3 and No.4 connection of after connection of middle three boxes, (d)Erection of columns and hollow slabs on the top of arch

It should be pointed out that box blocks will become independent box arches when the joint concrete reaches certain strength, and they can bear their own weight rather than relying on

Bailey arch. Thus, they not only aren't the load of the arch, but also contribute to stability of the box arch. Therefore, box arches should be tied with Bailey arch with steel wires.

After the middle three box blocks become independent arches, cast the concrete between the two side vertical webs, to make the three into a whole arch. Then, make them and the other two groups of ten units Bailey arch blocks into one arch.

4.4 Application for the construction of 133m box arch (referring to Table 2)

Table 2 : appliance for the construction of 133m box arch

NO.	Name	Weight (t)	subtotal (t)
1	Bailey steel arch construction	393	
2	Steel wires for stayed-cable	127	711
3	Universal members	191	
4	30T cable cranes	81	
5	Scaffold and template	80	330
6	2×16T gantry cranes	30	
7	Hoisting machinery	37	
8	Conveying machinery	35	
9	Concrete machinery	10	
10	Processing machinery	2	325
11	Slabs	180	
12	Equipment for water	110	
13	Equipment for electricity	40	
14	Others	50	
Totally 133m navigable span		1366	

5 CONCLUSIONS

Cable-stayed Bailey arch comprehensively utilizes Bailey steel arch and stayed-cables, and makes full use of their advantages to have construction more convenient, cheaper and safer. The segmental construction method on the Bailey arch not only improves the working site condition but also speed up the pace of the project.

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