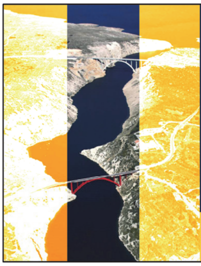

7th International Conference on Arch Bridges
ARCH'13
2 - 4 October 2013 Trogir - Split, Croatia
DESIGN AND CONSTRUCTION

SCHEME COMPARISONS OF NANPAN RIVER GRAND BRIDGE ON RAILWAY FROM YUNNAN TO GUANGXI

Xu Yong, Chen Kejian, Ren Wei, Hu Jintao, He Tingguo & You Lihui

China Railway Eryuan Engineering Group Co. Ltd, Chengdu, Sichuan province, China

Keywords: Yunnan-Guangxi railway, concrete arch bridge, steel truss arch bridge, concrete filled steel tubular arch bridge, scheme comparison.

Abstract: *Nanpan River Grand Bridge is a key project of the railway from Yunnan to Guangxi. According to the topography characteristics of the V-shaped canyon, deck arch bridge is clearly the best choice. Four types of arches including concrete box arch, twin-rib arch, box section steel truss arch and concrete filled steel tubular arch have been designed and compared. It is shown that a concrete arch bridge has sufficient stiffness, that can easily meet the requirements of train-bridge coupling dynamic analysis with cheaper costs than both steel trussed box type arch and concrete filled steel tubular arch. Twin-rib arch has no advantage in terms of material consumption and economic costs in comparison to box type arch. Considering the technology and construction convenience, arch bridge with single-box and three-cell section is finally selected. Three construction methods including the cable-stayed cantilever erection method, the Melan construction method and the combination method of both have been compared. It has been shown that the cable-stayed cantilever erection method has shortest construction time and lowest costs. But to reduce the construction risks and since construction time is not a controlling factor it was decided to apply the well known Melan construction method. The Nanpan River Grand Bridge is 852.43m long and 280m high. Its main bridge is a deck reinforced concrete arch bridge with the main span of 416m. The approach bridge and spandrel structures are set as 3×42m continuous beam + (60+104+60) m continuous rigid frame structure + 8×39.5m concrete continuous beam + 2-60m T-type rigid frame structure + 1×42m simply supported beam. The initial design began in June 2009 and the construction drawing design began in December 2009. The construction of this bridge started in August 2010. It is currently under construction and expected to be completed by 2015.*

1 GENERAL

The railway from Yunnan to Guangxi of 686.928km total length is an important artery for passenger and freight connecting southwest China and South China. It begins in Kunming City, Yunnan Province in the west and ends in Nanning City, Guangxi Zhuang Autonomous Region in the east. The railway is a passenger and freight line with the speed of 250km/h and spans across the Nanpan River between Mile County and Qiubei County. Within the possible area the line may pass through the terrain is mainly steep V-shaped canyons. No matter from the technical rationality or coordination with the natural environment, deck arch bridge is clearly the best choice. In the feasibility study phase, the design focuses on two bridge sites which are 20km apart. When deck arch bridge is adopted, the main span is about 400m at the lower level railway grade line , 360m at the higher level railway grade line. The geological report shows that there is a continuous fault fracture zone with the width of 60m along the close bank slope which has an influence on the skewback. So the main span has to be increased to above 500m for the lower level and 420m for the higher level in order to avoid the fault. Because of a smaller span, the bridge site at the higher level railway grade line is finally chosen, which also can meet the requirements of line direction and elevation.

The bridge site is located in the high mountains. The elevation of the ground is from 960m to 1520m. The relative height difference is 80～560m. The terrain at the bridge site is very steep and the vegetation is dense. Under the bridge at the side of Kunming, there is a 7m-wide highway road called provincial highway 305 from Qiubei County to Mile County. The bridge site is located in subtropical humid monsoon zone. Average annual temperature is 16.4℃, extreme maximum temperature is 34.9℃, extreme minimum temperature is -7.6℃, the highest monthly average temperature is 21.8℃ in July, the lowest monthly average temperature is 8.8℃ in January. Annual average wind speed is about 1.8m/s, the maximum wind speed is about 18m/s. The underlying bedrock is limestone and carbonaceous limestone. The basic capacity of W3 is 0.5MPa and of W2 is 1.0MPa. The peak ground acceleration at the bridge site is 0.116g. The characteristic period of ground motion response spectrum is 0.45s. The classification of the site is the class I.

Figure 1: The terrain characteristics at the bridge site

2 COMPARISIONS OF BRIDGE TYPES

Steel arch bridge and concrete arch bridge are traditional types and also are used widely. Since the 1990s, CFST arch bridge has emerged in China with the advantages of less steel consumption and convenient construction. In terms of deck arch bridge, the longest steel arch bridge is the New River Gorge Bridge in the United States with the main span of 518.3m. The longest concrete arch bridge is the Wanxian Yangtze River Bridge in China with the main span of 420m. The longest CFST arch bridge is the Zhijin River Bridge in China with the main span of 430m. The bridge span is about 420m. So the materials including concrete, steel and CFST are feasible for the arch ring. Besides, due to the longer span, the width of the arch ring needs to be wide which is contradictory with the narrow double line railway bridge deck. It seems that basket-type twin-rib arch bridge is more reasonable. At last, four schemes including deck steel truss arch, deck CFST arch, deck reinforced concrete twin-rib arch and deck reinforced concrete box arch are put forward and compared.

2.1 Deck Steel Truss Arch

Generally, when the span of steel arch bridge is over 200m, truss-type arch is more reasonable. Combining with transverse stiffness, basket-type truss arch bridge is adopted with the span of 416m, arch rise of 99m and rise to span ratio of 4.2. The approach bridge and spandrel structures are set as 3-42m prestressed concrete continuous beam +(60+104+60)m continuous rigid frame structure + 8-39.5m steel-concrete composite continuous beam + 2-60m T-type rigid frame structure + 1-42m simple supported beam, as shown in Figure 2. Longer span continuous rigid frame structures are used in order to decrease the height of spandrel columns and avoid the influences of excavation of the skewback on adjacent foundations. Steel structure is adopted for arch rib, spandrel columns and 8-39.5m continuous beam. The steel truss arch bridge has its advantages of relatively mature technology and relatively simple construction method. However, the controlling factor for the railway bridge is transverse stiffness which is the main technical characteristics and also the difficulty of the bridge, because members' dimensions, truss height, arch rib spacing and inclination angle are influenced by the transverse stiffness. After the comparisons of several arch widths, the arch rib center distance of 40 m at the arch springing, 16 m at the arch crown and inclined angle of 6.911° are determined through the vehicle-bridge coupling dynamic analysis. The total steel consumption is 28831tons (arch ring, spandrel columns and composite beam included). The whole bridge cost 675 million RMB.

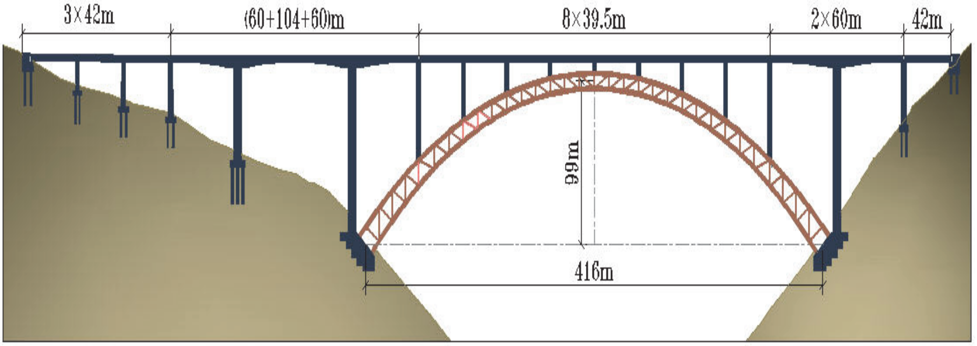

Figure 2: General layout of deck steel truss arch

2.2 Deck Concrete Filled Steel Tubular Arch

Concrete filled steel tubular arch bridge has developed very rapidly in the last 20 years in China. The longest bridge is the Hejiang River bridge with the span of 530m. If this bridge type is adopted, it can have the same general layout with the former scheme with the main difference of the arch rib structure, as shown in Figure 3. Each upper and lower chord member is composed of two steel tubes with the diameter of 1600mm and the thickness of 20mm. The concrete (C55) is pumped into the steel tubes after the closure. To lower the gravity center and increase transverse stiffness of the structure, the full-web type is used for the lower arch rib from arch foot to the first spandrel column and the truss type is used for the rest middle part. The transverse distance between two pieces of arch ribs is 36m at the arch foot and 12m at the arch crown. The inclination angle of the arch ribs and spandrel columns is 6.991°. The total steel consumption is 20035 tons. The whole bridge cost 531 million RMB.

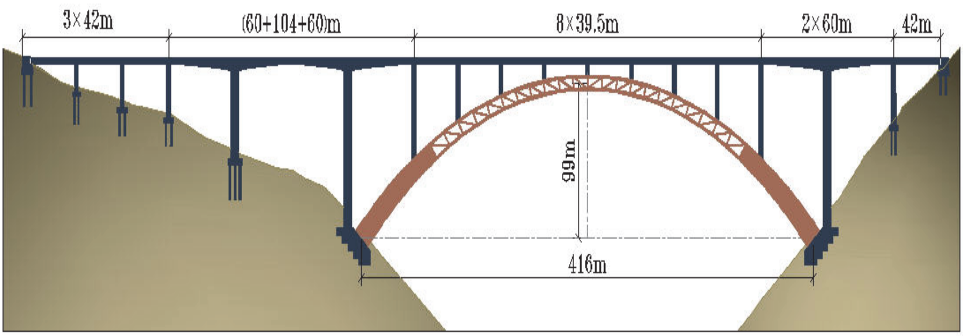

Figure 3: General layout of deck CFST arch

2.3 Deck Concrete Twin-rib Arch

In terms of concrete arch, both schemes of twin-rib arch and whole-box arch are feasible. Under the same transverse stiffness, basket-type twin-rib arch seems more economical. The general layout is the same with the former. The catenary is used as arch axis of the main bridge with arch span of 416m, arch rise of 99m and rise to span ratio of 4.2. Nine transverse beams are set at the pier position between two arch ribs. Concrete is used for spandrel columns and beams. The arch ring adopts box section with variable height from 7m to 11m and variable width from 4.5m to 7.5m. The transverse distance between the two arch ribs is 30m at the arch foot and 9m at the arch crown. The inclination angle of the arch ribs is 6.054°. Melan construction method is used for the arch ring. Steel tubular truss is used as the construction frame during pouring the concrete of arch ring. After the closure of steel tubular truss, concrete with the grade of C80 are pumped into steel tubes. Unlike other schemes, this scheme adopts embedded rock foundation which is directly embedded into the ground. The total volume of arch concrete is 23559m^3 and the steel consumption is 4423 tons. The whole bridge cost 441 million RMB.

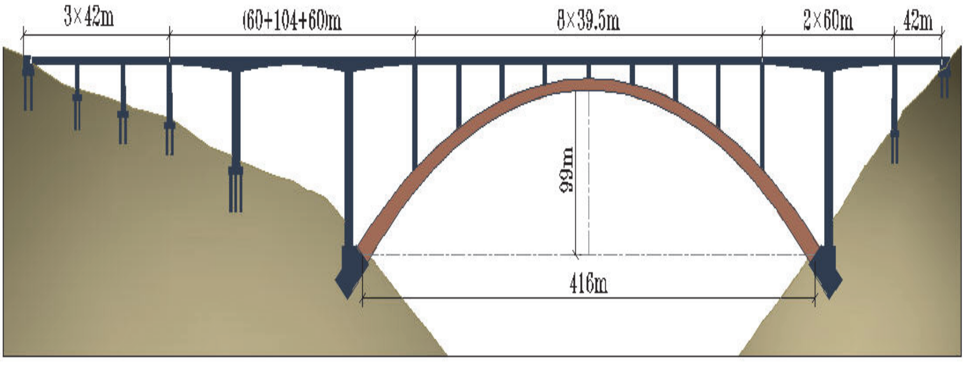

Figure 4: General layout of deck concrete twin-rib arch

2.4 Deck Concrete Single Box Arch

The general layout of concrete single box arch is the same as that of a twin rib arch. The catenary is used as arch axis of the main bridge. The arch ring adopts single-box and three-room section with equal height of 8.5m and variable width from 18m to 28m. The width of the section at the arch springer is 28m. The width of the section within the scope of 286m in the middle is 18m. The width of the section between the arch springer and the distance of 65m from the arch springer varies from 28m to18m linearly. Concrete structure is used for spandrel columns and beams. Melan construction method is used for the arch ring. The total volume of arch concrete is 24068m^3 and the steel consumption is 4011 tons. The whole bridge cost 446 million RMB.

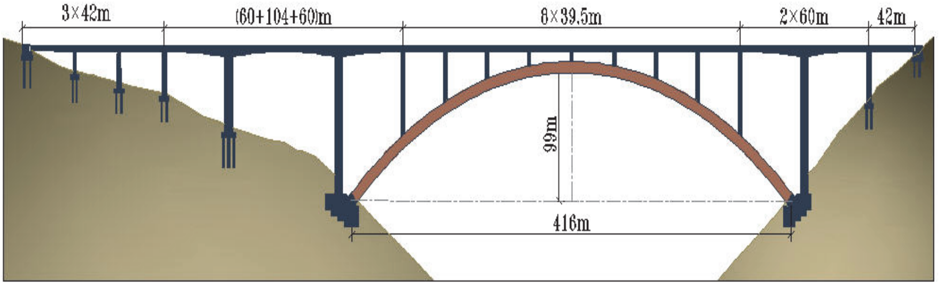

Figure 5: General layout of deck concrete whole-box arch

2.5 Comparisions Of Four Bridge Types

Under the circumstance of relatively cheap labor costs in China, the cost of the bridge is almost determined by steel consumption. Among four schemes, steel truss bridge is the most expensive and hence firstly eliminated. CFST Bridge costs 100 million more than other two concrete arch bridges. But its construction period is at least 2 years shorter than the other two concrete arch schemes. CFST arch bridge is mainly used in highway bridges in China and less used in railway bridges. Beipan River Bridge on the railway from

Shuicheng to Baiguo, built in 2001 which was designed by CREEC is a CFST arch bridge with the span of 236m. The structural form is similar to the CFST arch scheme of this bridge. The truss arch members and bracings are assembled on the scaffold of the hillside. When all the steel tube joints are completely welded , the arch truss is rotated horizontally and the closure made. Due to the lack of swing construction conditions, steel tubular arch truss has to be erected and welded in the air. So it cannot be sure whether high-precision assembly can be accomplished, which is critical for a railway bridge because of fatigue. Besides the high costs, the welding quality can not be guaranteed which is also the important reason why this scheme is discarded.

According to the whole railway construction organization plan, even if the construction period of Nanpan River Bridge is 5 years, it will still not affect the whole line construction arrangement. So the concrete arch scheme with relatively cheap cost is prominent. Comparing concrete box arch with basket-type twin-rib arch, the material consumption and the cost are very close. It depends on the aesthetics and construction difficulties to make the choice. In terms of aesthetics, it is hard to tell which one is better. In terms of construction difficulties, based on the same construction method, it is much easier to manufacture and erect a steel tubular truss. From another construction point of view, there are more options for construction unit if whole-box arch is adopted, such as cable-stayed cantilever erection. In addition, the Wanxian Yangtze River Bridge and Krk Bridge, the world's first and second longest concrete arch bridge, both adopt single-box and three-room section. From technical criteria and construction convenience, a single box arch was finally chosen in the preliminary design stage, as shown in Figure 6.

Figure 6: Rendering of deck concrete single box arch

3 CONSTRUCTION DESIGN

3.1 General

The total length of the Nanpan River Bridge is 852.43m. The main bridge is a deck reinforced concrete arch bridge with the span of 416m. The deck is 280m above the bottom of the river. The approach bridge and spandrel structures are set as 3-42m continuous beam + (60+104+60)m continuous rigid frame structure + 8-39.5m prestressed concrete continuous beam + 2-60m T-type rigid frame structure + 1-42m simple supported beam. The arch ring (C60 concrete) adopts single-box and three-room section, as shown in Figure 7 and Figure 8.

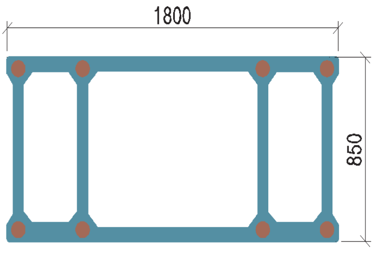

Figure 7: Arch section at the arch crown (unit: cm)

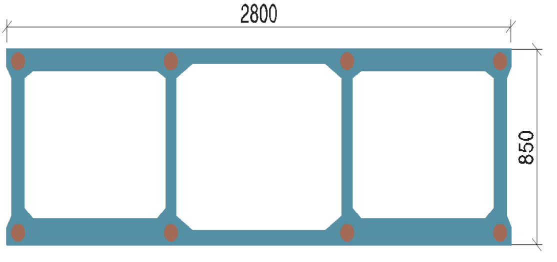

Figure 8: Arch section at the arch springing (unit: cm)

Double-column rigid pier is used for the approach piers and spandrel columns. The concrete grade for piers is C40. The junction pier is 102m high and the highest spandrel column is 58m high. The longitudinal width of the junction pier is 7.5m. Transverse medial distance between the double columns remains the same. Two slopes are set at the outside of two columns. One is 1:25 from the top to the distance of 50m from the top. The other is 1:15 from the distance of 50m to the distance of 102m from the top, as shown in Figure 9. The hollow type cross section is adopted for No.1-3 columns and the solid section for No.4-5 columns. No.1 column is shown in Figure 10.
2-60m prestressed T-type rigid frame structure and (60+104+60) m continuous rigid frame structure adopt single-cell box girder, as shown in Figure 11. Its width is 13.4m at the top and 8.0m at the bottom. The depth of the cross section is 7.5m at the supports and 4.0m at the middle and end of the beam. 1-42m simple supported beam, 3-42m continuous beam and 8-39.5m continuous beam adopt box girder with the same outer dimensions for saving formwork and convenient construction. The sections are shown in Figure 12. The concrete grade for girders is C55.

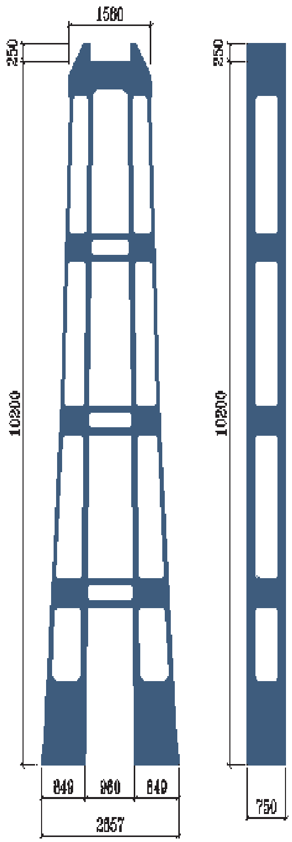

Figure 9: Junction pier (unit: cm)

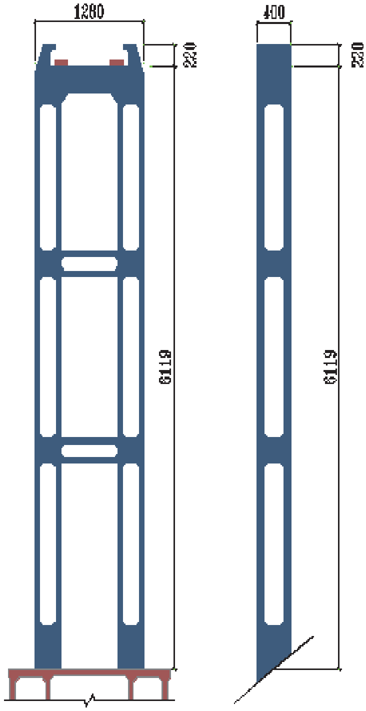

Figure 10: No.1 spandrel column (unit: cm)

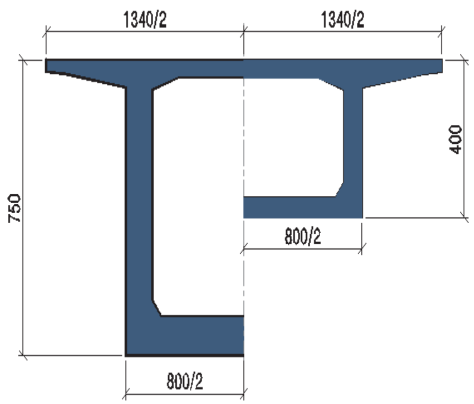

Figure 11: Typical section of (2-60m) T-type frame structure (unit: cm)

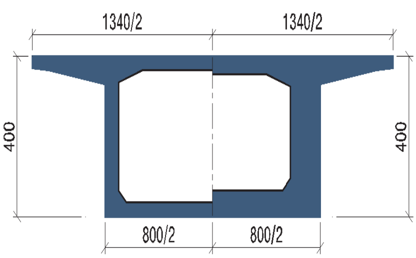

Figure 12: Typical section of (8-39.5m) continuous beam (unit: cm)

3.2 Comparisions On Construction Methods

Melan construction method for the arch ring is safe and feasible, like the Wanxian Yangtze River Bridge. So it is recommended in the preliminary design stage. When it comes to the construction stage, the construction unit will reevaluate various possible construction methods with he design unit. Based on Melan construction method, cable-stayed cantilever erection method and the combination method are proposed.

(1) Cable-stayed Cantilever Erection Method

Cable-stayed cantilever erection method is used mostly for European and American long concrete arch in recent years, such as Mike O'Callaghan-Pat Tillman Memorial Bridge in America with the span of 323m (built in 2010), Froschgrundsee bridge in German with the span of 280m (built in 2006) and Svinesund Bridge in Sweden (built in 2005). It has the advantages that: it does not need falsework, arch ring concrete is cast in-site at one time, simple technology and fast construction speed. The volume of concrete is about 24000m^3. To reduce the erection weight, it is proposed to first cast side cells concrete symmetrically by using four moveable formwork carriagesb until the closure at the arch crown. Then the top and bottom chords of the middle cell are to be cast The arch ring is divided into 76 segments of 6m length. The maximum segment weight is approximately 390 tons. The schematic diagram of cable-stayed cantilever erection method is shown in Figure 13. The main temporary works include: buckle and back cable system, temporary tower frame on top of the junction pier, rock anchor engineering, four moveable formwok carriages, cable crane (40t), etc. All the temporary engineering cost 85-95 million RMB. The construction period is about 18 months.

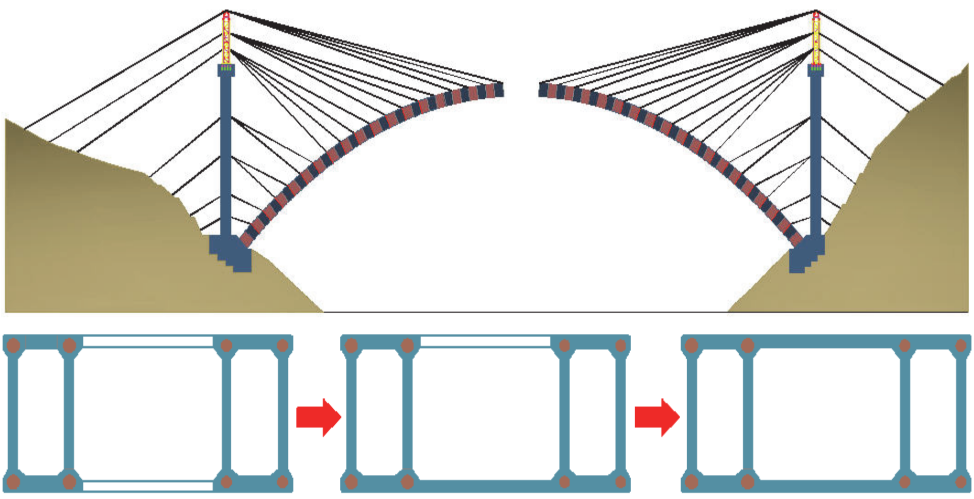

Figure 13: Schematic diagram of cable-stayed cantilever erection method

(2) Melan Construction Method

Steel tubular truss is used as the construction frame during pouring the concrete of arch ring. It is divided into 38 segments of 12m length. The maximum segment weights approximately 150 tons. Steel tubular frame members are manufactured in the factory in Wuhan, transported to assembling yard near the bridge site through railway and highway, welded into the segment in the yard, and then erected on the lifting platform under the bridge by cable crane. Typical section of steel tubular truss is shown in Figure 14. After the closure of the truss concrete is pumped into steel tube. Then arch ring concrete is cast by using six working faces in order to keep balance, as shown in Figure 15 and Figure 16. The main temporary works include: steel tubular truss, cable crane (140t), assembling yard and formwork, etc. All the temporary engineering cost 100-110 million RMB. The construction period is about 48 months.

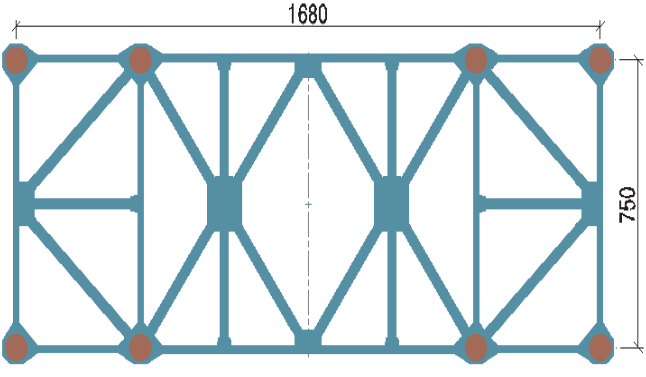

Figure 14: Cross section of steel tubular truss at the arch crown (unit: cm)

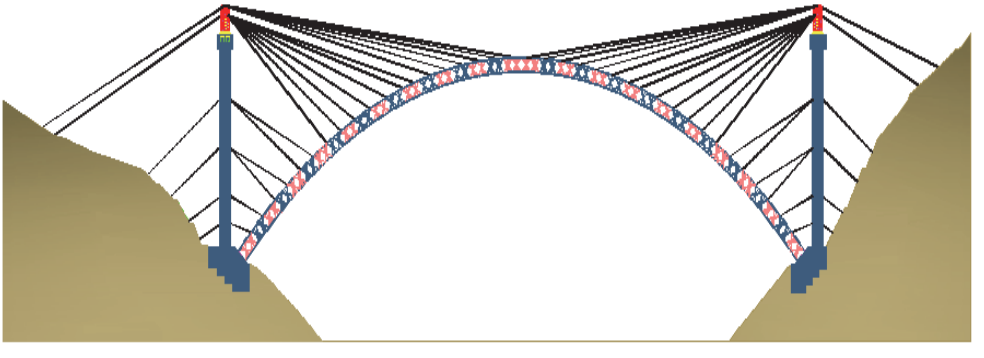

Figure 15: Construction diagram of erecting steel tubular truss

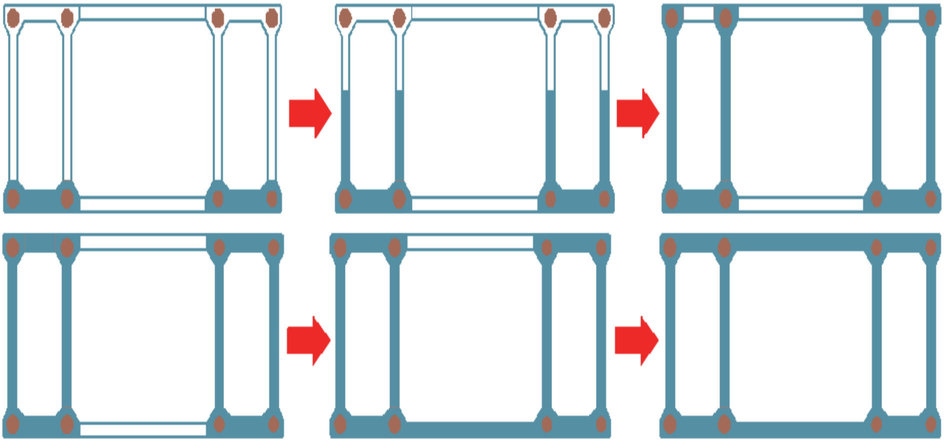

Figure 16: Construction diagram of casting the arch ring concrete

(3) Combination Method Of Cantilever Erection And Melan Construction

Combination method means cantilever erection used for arch ring at the arch springing and Melan construction method used for arch ring at the arch crown. Firstly, two side cells are cast by using cable-stayed cantilever erection method and a steel tubular truss with a length of 116m is assembled. When cantilever length reaches 150m, the truss (about 1000tons) will be lifted to the right position. After the completed erection, concrete is pumped into the steel tube. Then side cells are concreted by using moveable formwork carriages until the closure. Finally, bottom and top plates of the middle cells are cast. The construction diagram is shown in Figure 17. The main temporary works include: buckle and back cable system, rock anchor engineering, climbing hanging basket, cable crane (40t), lifting platform and hoisting equipment, etc. All the temporary engineering cost 105-110 million RMB. The construction period is about 20 months.

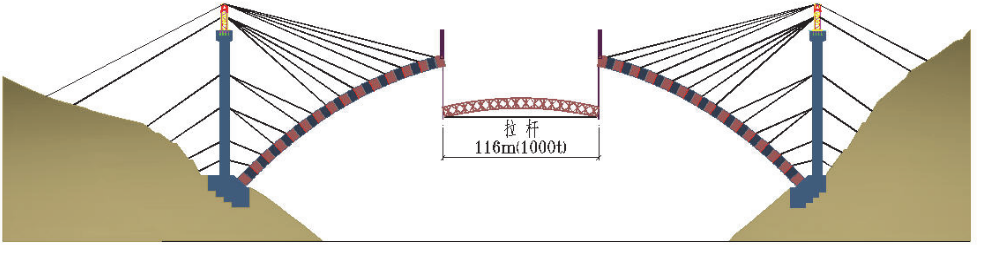

Figure 17: Construction diagram of combination method

(4) Comparisions And Conclusions

Both in regard to the length of construction and to costs, cable-stayed cantilever casting method is the best choice. Combination method ranks second and Melan construction method ranks third with the longest construction period and highest costs. This also shows why cable-stayed cantilever construction method is so popular in European and American countries. However, it is less used in China and the longest span concrete arch which used the method is 150m. Because of being unfamiliar with this method, the construction unit

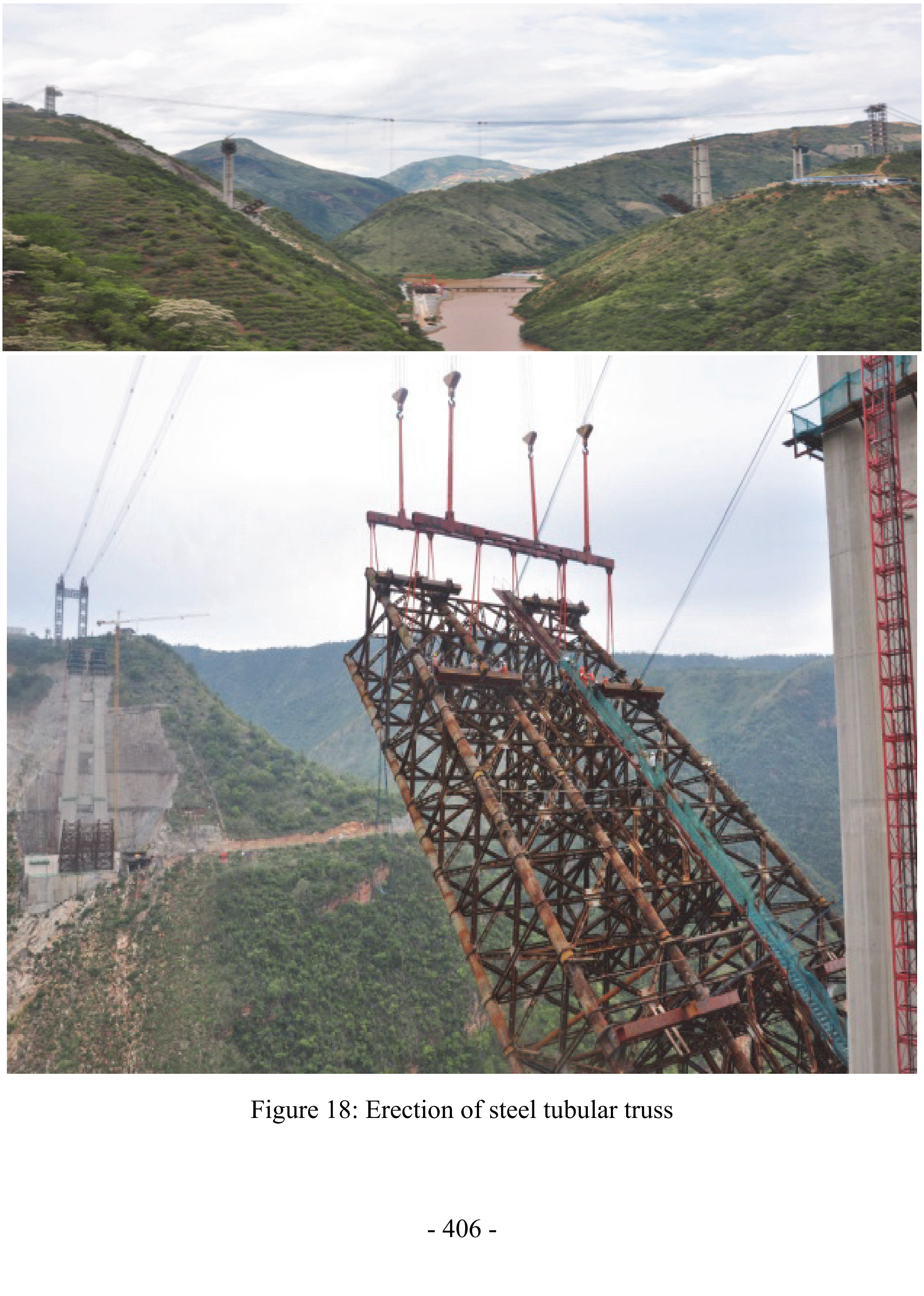

Figure 18: Erection of steel tubular truss

and many experts reject it. Detailed geological survey shows that geological conditions at both sides are far worse than expected. The back cable length at Nanning side will be more than 70m which is difficult to construct. Meanwhile, a big safety risk exists. So although it has some advantages, it can hardly be accepted by the construction unit and also can hardly be supported by the experts. And contractor has the final decision of construction method. So as designers, we should fully respect the opinion of contractor. From the structural behavior, it is beneficial to adopt Melan construction method. Steel truss plays an important role in casting arch ring concrete. When the bridge is completed, it will contribute less because of a small proportion compared with arch ring concrete. However, because the bridge is located in 7 degree seismic zone, the consumption of steel bars will be reduced by 1500 tons, if half truss is considered in the seismic calculation. Finally, Melan construction method, which is the most common in China, was adopted. The erection of steel truss is shown in Figure 18. The whole bridge is expected to be completed by June, 2015.

REFERENCES

[1] Xu yong, Chen Kejian, Hu Jingtao, and Ren Wei., 2009. Feasibility study on Yunnan-Guangxi railway, Chengdu, China Railway Eryuan Engineering Group Co., Ltd. (in Chinese)

[2] Xu yong, Chen Kejian,Hu Jingtao, and Ren Wei 2009. Preliminary design on Yunnan-Guangxi railway, Chengdu, China Railway Eryuan Engineering Group Co., Ltd. (in Chinese)

[3] Xu yong, Chen Kejian,Hu Jingtao, and Ren Wei 2010. Reseach reports of Nanpan River large bridge on Yunnan-Guangxi railway, Chengdu, China Railway Eryuan Engineering Group Co., Ltd. (in Chinese)

[4] Technical Summary of Wanxian Yangtze River Highway Bridge. 2001. Sichuan Province, University of Electronic Science and Technology Press. (in Chinese)