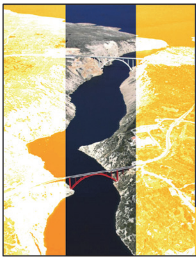

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DESIGN AND CONSTRUCTION

SCHEME COMPARISON OF BEIPAN RIVER BRIDGE SITE, LINE HEIGHT AND BRIDGE TYPE ON SHANGHAI-KUNMING PASSENGER DEDICATED RAILWAY

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Keywords: High speed railway, bridge site, line height, bridge type, scheme comparison, suspension bridge, inclined leg arch bridge, steel truss arch bridge, concrete arch bridge.

Abstract: *Beipan River Grand Bridge is one of the important bridge engineering projects in selecting railway alignment. Three possible bridge sites Dapo, Guangzhao, Bangongpo are selected within the range of 20km in the possible area and compared. The railway slope of 30‰ must be adopted for Bangongpo bridge site which has impact on traffic speed. The terrain at Dapo bridge site is steep and inaccessible. More importantly, karst is so developed and has a great impact on tunnel engineering on both sides of the bridge. After a comprehensive screening, Guangzhao bridge site is identified as the preferred site. At Guangzhao bridge site, three different levels (990m、880m、815m) at the top of rail (grade lines) are considered.（96+144+792+144+96）m suspension bridge is considered for the high level of 990m. Concrete arch bridge, steel truss arch bridge and steel cable stayed bridge are considered for the middle level of 880m and the deck concrete arch bridge with the main span of 445m is preferred.（80 + 2×144 + 80）m concrete inclined leg arch bridge which is preferred and concrete arch bridge are considered for the low level of 815m. The design speed for this railway line is 350km/h. For the high level of 990m, when the train passes through the suspension bridge, the speed must be limited to 200km/h which is bad for operation management. For the low level of 815m, the tunnel engineering in both sides must pass through the horizontal seepage zone of karst which has impact on construction safety. After a comprehensive comparison, the middle level of 880m is finally chosen. In such V-shaped canyon, arch bridge is clearly the best choice and the comparisons of concrete arch bridge and steel truss arch bridge are made. Since the construction period is not a controlling factor, concrete arch bridge with high stiffness and economical cost is favorable.*

1 INTRODUCTION

Shanghai-Kunming passenger dedicated line is the most important traffic artery, connecting southwest, South and East China. It begins in Shanghai, via Zhejiang (Hangzhou City), Jiangxi, Hunan(Changsha City), Guizhou, and ends in Kunming City of Yunnan Province with the total length of 2264km. The railway construction is divided into three sections. The first section from Shanghai to Hangzhou was opened in 2011. Hangzhou-Changsha section and Changsha-Kunming section was started in 2009. The technical standards for the whole line differ slightly. The maximum speed is 350km/h for Shanghai to Changsha and 250km/h for Changsha to Kunming. However, major engineering effort is required to design according to the speed of 350 km/h. Beipan River Grand Bridge is located in Guizhou Province. It is close to Guanling County in the east, next to Jinglong County in the west. The geology of bridge site area is the most complicated. In addition to deep V-shaped canyon, there is some unfavorable geology like coal seam gas, goaf, karsts, dangerous rock fall and potential landslides. So when selecting the bridge site, some relevant construction risks should also be considered.

2 BRIDGE SITE

The Beipan River belongs to the Pearl River water system. After joining the Nanpan River in Guangxi Province, it is known as the Hongshui River. When entering into Guangdong Province, it is called the West River. When joining the Dongjiang River, it is known as the Pearl River, and finally flows into the South China Sea. In the Guangzhou Province, the terrain drops dramatically. The formation lithology is mainly limestone, and also mixed with sandstone, mudstone and coal-bearing strata and so on. In addition to the influences of topographical and geological conditions, the adjacent engineering also should be considered when selecting the bridge site. According to 1/10000 topographic maps and field exploration, three most valuable bridge sites have been chosen which are Dapo bridge site at the upstream side, Guangzhao bridge site at the midstream side and Bangongpo bridge site at the downstream side, respectively, as shown in Figure 1. The comparisons between three bridge sites have been carried out.

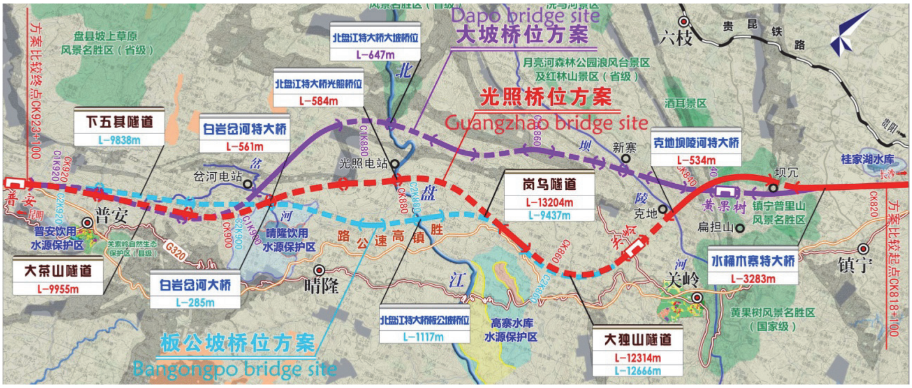


Figure 1: Plan view of three bridge sites

Dapo bridge site is located in the reservoir area of the Guangzhao hydropower station, about 8km from the dam. The obstacle at this bridge site is minimum among three bridge sites. However, there are some unfavorable factors. Firstly, the railway line passes through Maokou area which is very famous for the developed karsts. So the risk of appearance of karst caves and even large rivers within the range of bridge foundation and long tunnel is very high. Secondly, bank slope at the bridge site is very irregular and deep, and stability is bad. Thirdly, the transportation condition is very bad and there is no access to the bridge site. Fourthly, from the bridge site to Huangguoshu town, the railway line must pass through the goaf which has hundreds of years' history. And the specific location of the mine could not be identified, that leaves some hidden troubles for engineering. Bangongpo bridge site is located between Guangzhao hydropower station and Beipan River Highway Bridge, about 10km from the station. The river at this bridge site is very wide. Sharp down grade (maximum 30 ‰) must be adopted for the bridge to reach the appropriate level which has a great influence on the speed. Also, due to the lower line level, the buried depth of tunnel increases and the risk of being on the karst horizontal seepage belt increases.
Geological conditions are relatively good near the downstream of the Guangzhao dam. This is why the dam was built here. Guangzhao bridge site is about 2km from the downstream of the dam. V-shaped canyon is just orthogonal to the railway line and the slope surface is smooth. Bedrock is mainly limestone and dolomite. The karst is undeveloped. There are highways on both sides under the bridge. So transportation condition is very good. Also because the highway at Qinglong side is in the tunnel, foundation excavation has a smaller impact on the highway. The costs of three bridge site schemes have been compared. If the cost for the Guangzhao bridge site is zero, the cost is 120 million RMB for Dapo bridge site and 500 million RMB for Bangongpo bridge site. After taking into account all these factors, Guangzhao bridge site is finally chosen for Beipan River super large bridge. The bridge site screening work has been done during the pre-feasibility study stage and feasibility study stage. And it has been approved by the ministry of railways.

3 LINE LEVEL AND BRIDGE TYPE

From the regional geological analysis, the bridge is still in the karsts development area, especially Guangzhao tunnel at Guan ling side. Geological analysis showed that the risk of being in the large-scale karsts is very high. To reduce the impact of karsts on the tunnel and ensure construction safety, the line level should be raised as soon as possible to meet the requirements of tunnel and geology. So in the preliminary design stage, the line height of Beipan River Bridge has been studied and three different line heights (990m, 880m and 815m) are chosen and compared.

3.1 Scheme for the high line level

The level of 990m at the top of rail is used for the high line. Due to the large span, arch bridge and girder bridge type are inappropriate. Instead, suspension bridge type and cable-stayed bridge type are feasible. If cable-stayed bridge is adopted, the height of the pylon reaches to 200m and the length of stiffened girder will be 1600m. It is not a best choice in terms of aesthetics and engineering costs. So the suspension bridge type is recommended for the high line level. It has a total length of 1653.4m, with a span arrangement of 1-24m simple supported box beam+3-32m simple supported box beam+ (96+144+792+144+96)m suspension bridge+6-32m simple supported box beam+2-24m simple supported box beam, as shown in Figure 2. The sag is 66m, and the sag to span ratio is 1/12. Gravity type anchorage is adopted. The stiffening truss girder is 15m high and 25m wide with the panel length of 12m. The distance between the hangers is 25m. H-shaped concrete pylon is used for the pylons which is 160m high at Shanghai side and 163m at Kunming side. The total cost is about 1.576 billion RMB.

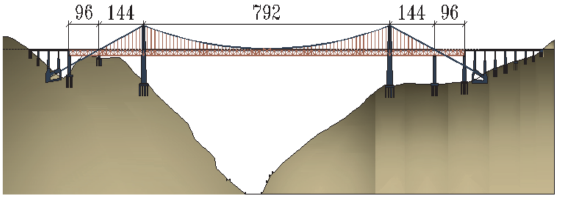


Figure 2: General layout of the suspension bridge for high

The scheme of high line level meets the requirements of the tunnel to the maximum extent. However, the cost of bridge engineering will be increased by several times. Besides, most importantly, according to the train- bridge coupled dynamic analysis, when the train passes across the suspension bridge, the speed must be limited to 200km/h which is bad for operation management.

3.2 Scheme for the low line level

Generally, low line level is used for mountain railways. When the tunnel length is not increased too much, replacing long-span bridges with long tunnels has its economic advantages. The longitudinal slope at both sides of the bridge has reached its limit, and cannot be lowered any more. The arch bridge for the low line level is obviously the best choice. Two schemes of arch bridge have been studied. The first one is traditional deck concrete arch bridge with the span of 340m. Melan construction method or cable-stayed cantilever construction method can be used to erect the arch ring, as shown in Figure 3. The other one is inclined leg arch bridge with the span of 260m, as shown in Figure 4. Spandrel beam adopts prestressed concrete continuous beam. The swing construction method is considered to erect the arch ring. Both schemes are satisfying from aesthetical point. However, in terms of structural type and construction method, inclined leg arch bridge seems to be more innovative which is recommended.

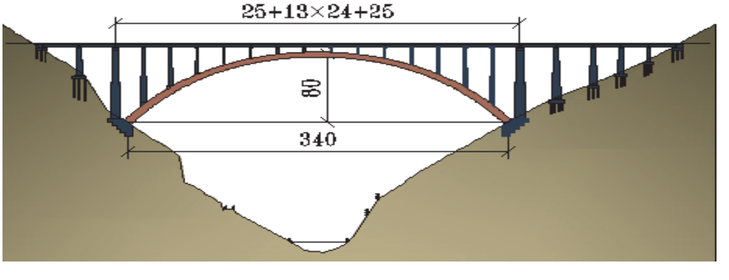


Figure 3: General layout of deck reinforced concrete arch bridge (unit: m)

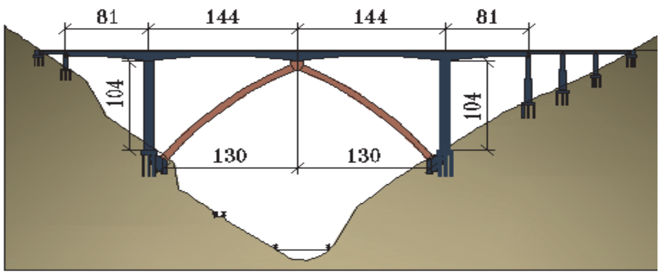


Figure 4: General layout of inclined leg arch bridge (unit: m)

3.3 Scheme for the middle line level

Due to the high speed of 350km/h, bridge structure should satisfy the requirements of safety and comfort, when train passes across it. It means the structure should have enough vertical and lateral stiffness which is the primary consideration for choosing the bridge type. Cable-stayed bridge and suspension bridge, in general, belong to flexible structural systems. To meet the requirements of train-bridge coupling dynamic analysis, the cost must be very high. In fact, middle line level is obtained from setting arch bridge with the span from 400 to 500m, and then the comparisons of bridge schemes are made at this level. In other words, for the middle line level of 880m, the bridge will be sure to meet the functional requirements of high-speed railway. Five bridge type schemes have been studied including a cable-stayed bridge, a through steel truss arch, a half though steel truss arch, a deck steel truss arch and a deck concrete arch.

The span arrangement of cable-stayed bridge is（168+336+168）m, as shown in Figure 5. Regarding both, the functional requirements and matching with terrain, it is not a good choice. So, it is the first to be eliminated.

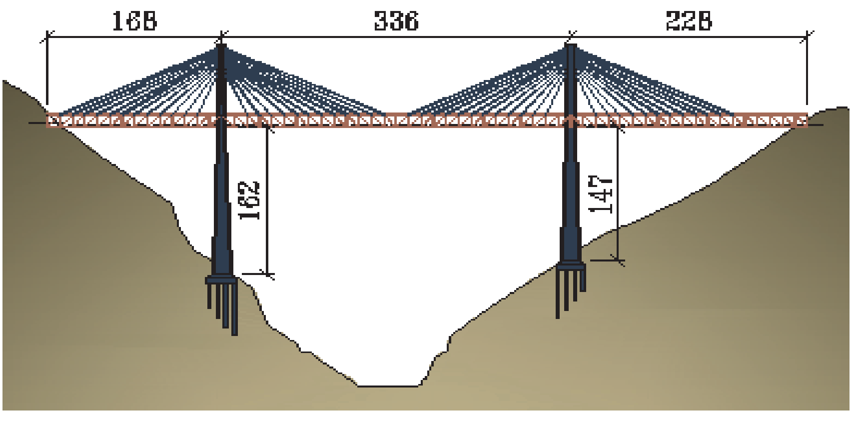


Figure 5: General layout of the cable-stayed bridge（Unit: m）

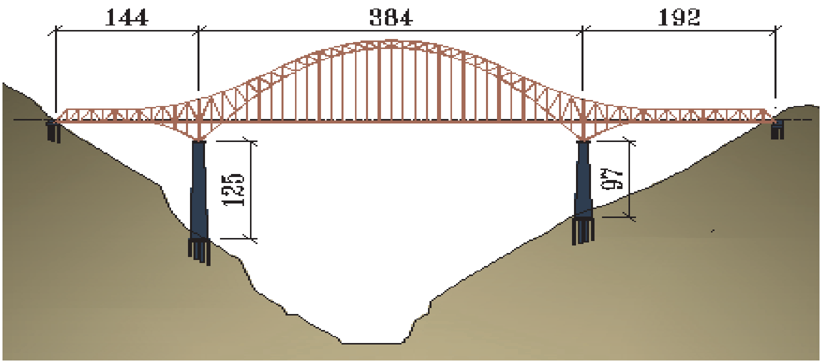


Figure 6: General layout of through steel truss arch （Unit: m）

Inspired by Dashengguan Large Bridge, the scheme of a through steel truss arch is proposed with the span arrangement of（144+384+192）m, as shown in Figure 6. Theoretically, this scheme can satisfy the requirements of train-bridge coupling dynamic analysis. But it will cost much more. Besides, the thrust force of the arch bridge needs to be balanced by the tension in the stiffening girder. And it is not worthwhile not to take advantage of very good foundation conditions. Taking into account other factors such as high center of gravity and high cost, this scheme is also easily eliminated.
The half through steel truss arch with the span of 560m is shown in Figure 7. If adopted, it will be the largest steel arch bridge in the world when completed, and of course the largest arch bridge in the world. With the advantages of low center of gravity and no high spandrel columns, it is favorable to meet the dynamic requirements. However, it has the same problems as the through steel truss arch. The deck width determined by transverse stiffness is much greater than that double-track railway need. Because of the large span, overall cost of the scheme is very high. If there is no other factor to intervene, it is difficult to be accepted, so it is eliminated too.

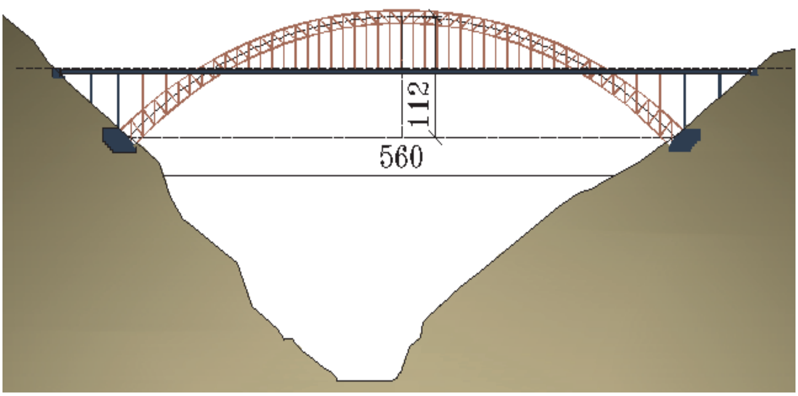


Figure 7: General layout of half through steel truss arch（Unit: m）

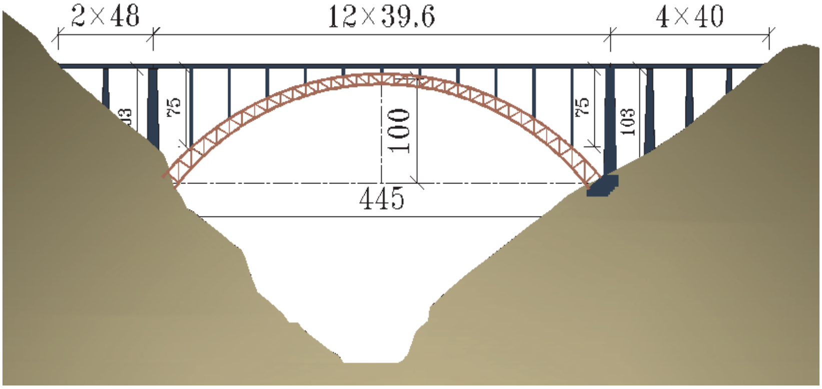


Figure 8: General layout of deck steel truss arch（Unit: m）

For the middle line level, two most competitive schemes are a deck concrete arch and a deck steel truss arch with the span of 445m, as shown in Figure 8 and Figure 9. In the preliminary design phase, the comparisons of these two schemes have been made. Melan construction method is adopted for concrete arch bridge. The construction period is about 4.5 to 5 years. Steel truss arch bridge adopts cable stayed cantilever construction with the period of 3.5 years. Because of the low labor costs in China, although the construction period of concrete arch is 1/3 longer, the total costs are nearly 40% cheaper than steel truss arch.

Besides, the deck steel truss arch also has its own shortcomings. In order to meet the requirements of the stiffness, the strength is not just a controlling factor and the steel consumption has to be increased. For the concrete arch, because of the difficult construction method and longer period, whether it can satisfy the requirements of the whole line construction organization plan, is the key. For the section from Guiyang to Kunming, the project controlling the whole-line construction period is Bibanpo Tunnel with the construction period of 5.5 to 6 years. So 5 years' construction period of concrete arch bridge will not matter. So the concrete arch bridge is the most reasonable scheme, which is recommended.

3.4 Final decision

Among three line height schemes, the total cost of bridge and tunnel engineering decreased with the decrease of line level. At the preliminary design review meeting, the middle line level scheme is selected by the ministry of railways. For the high line level, when the train passes across the suspension bridge, the speed must be limited to 200km/h which is bad for operation management. So, it is eliminated. Although middle line height is 65m higher than low line height, it is very good because it reduces the risk of tunnel construction. Also, at this level, the bridge type scheme is relatively mature and can meet the functional requirements very well. Also, review opinions shows that the reinforced concrete deck arch bridge is to be used for the bridge.

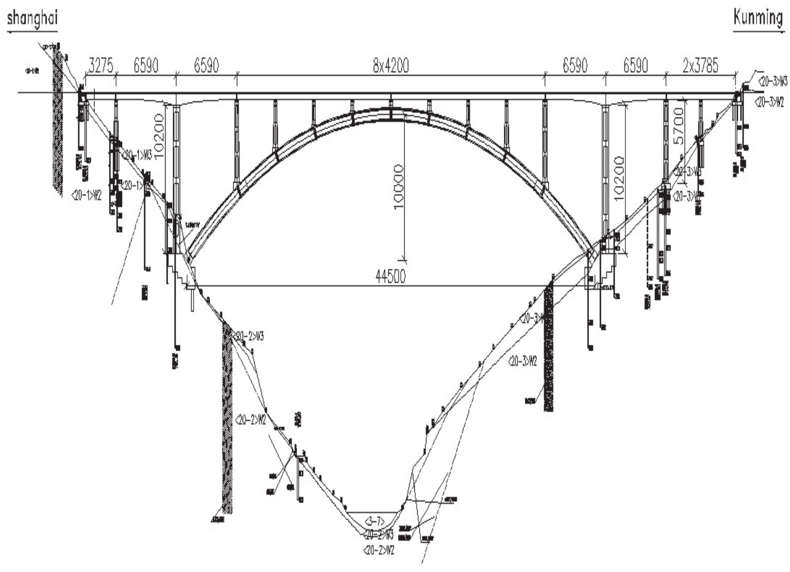


Figure 9: General layout of deck reinforced concrete arch bridge at the middle line level (unit:cm)

4 BRIDGE DESIGN

4.1 General

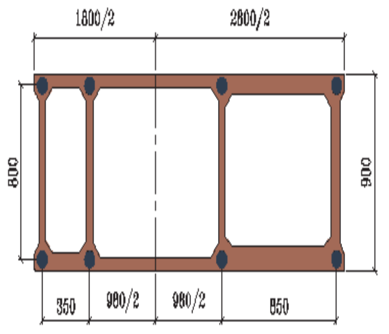
The river bed at the bridge site is about 60m wide and 4-7m high. The terrain at both sides is very steep and the deck is about 300m above the bottom of the valley. The bridge site is located in subtropical humid monsoon zone. Average annual temperature is 15 ~18℃, extreme maximum temperature is 32.6℃, extreme minimum temperature is -4℃. Annual average wind speed is about 4m/s, the maximum wind speed is about 25m/s. The underlying bedrock is mainly dolomite, argillaceous dolomite, brecciaed dolomite, dolomitic limestone and brecciaed limestone. From small mileage side to large mileage side, basic bearing capacity of weakly-weathered bedrock (W2) is 0.9, 0.85 and 0.8MPa, respectively. The peak ground acceleration at the bridge site is 0.089g. The characteristic period of ground motion response spectrum is 0.65s. The classification of the site is the class I. Main technical standards: double-line passenger dedicated line; non-ballasted track; highest design speed of 350km/h; ZK live load; Distance of tracks: 5m.

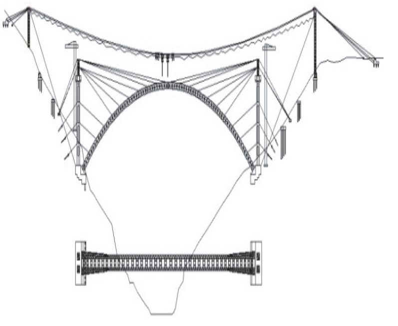
Figure 10: Rendering of bridge

The center mileage of this bridge is D1K881 +943.0. Its total length is 721.25m. The span of main bridge is 445m. The approach bridge and spandrel structures are set as 1-32m concrete simple supported beam + 2-65m prestressed T-type rigid frame structure + 8-42m prestressed concrete continuous beam + 2-65m prestressed concrete T-type rigid frame structure + 2-37m prestressed concrete continuous beam. In the construction design, structural details are taken into consideration in terms of aesthetics. The bridge rendering is shown in Figure 10.

4.2 Structural design

The concrete grade for the arch ring is C60. The catenary shape is used as arch axis of the main bridge with arch span of 445m, arch rise of 100m and arch-axis coefficient of 1.6. The arch ring is a three cell single box type section with constant depth of 9.0m and variable width from 18m to 28m. The width of the section at the arch springer is 28m. The width of the section between the distance of 65m from the arch springer and the arch crown is 18m. The width of the section between the arch springers and the distance of 65m from the arch springers varies linearly from 28m to18m. The sections at the arch springer and the crown are shown in Figure 11. 2-65m prestressed T-type rigid frame structure is a single box type girder. Its width is 13.4m at the top and 8.0m at the bottom. The depth of the section is 7.5m at the supports and 4.0m at mid-span and at ends of the beam. Approach beams and arch superstructures adopt box type girder with the same outside dimensions for saving formwork and convenient construction. Double-column rigid pier is used for the approach piers and spandrel columns. The junction pier is 102m high; the highest spandrel column is 58.9m high. Open-cut foundation is used for skewback and pile foundation is used for the rest.





Half arch crown section Half arch Springer section

Figure 11: Arch section (unit: cm) Figure 12: Construction diagram

4.3 Construction method

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 of C80 grade is pumped into steel tubes. Then arch ring concrete is cast by using multi working faces in order to keep balance. In order to reduce the concrete stress at the arch foot, the whole section at the arch foot is first formed. Cantilever erection method is used to construct 2×65m T-type rigid frame structure. The approach bridge superstructure and continuous beams are cast in-situ on scaffolding.

Steel tubular frame is composed of four truss parts. Upper and lower chords (steel grade Q370qc) are composed of 8 steel tubes with a diameter of 750mm and a thickness of 24mm. Web members and bracing system members (steel grade Q345B) adopt hot-rolled angle composite members. Steel tubular frame members are manufactured in the factory in Wuhan, transported to assembling yard near the bridge site by railway and on highway, welded into the segment with the length of 12m in the yard, and then erected on the lifting platform under the bridge by cable crane. There are 40 segments to erect. When erecting each two segments (24m), one pair of buckle and back cables are tensioned.

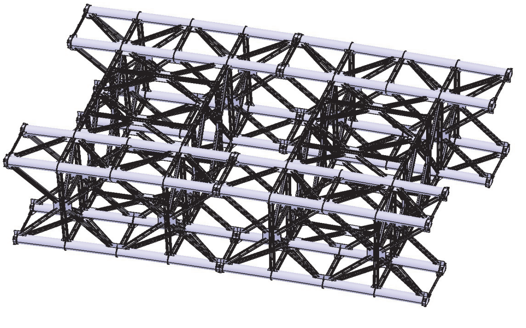


Figure 13: Segmental model of steel tubular truss by CATIA

5 CONCLUSIONS

Beipan River Super-Large Bridge is one of the important bridge engineering projects in China's railway system. When completed, it will be the largest span reinforced concrete arch bridge in the world. In the screening process of bridge site, line height and bridge type, many expert engineers specializing in railway engineering, geology engineering, bridge engineering and tunnel engineering worked together and cooperated closely so that work has been carried out smoothly. At all the previous scheme-reviewing meetings from pre-feasibility study stage to preliminary design stage, the scheme design has been approved by all the experts. Besides, there has been extensive geological survey work, that is very rare in the design of similar large span bridges. The project started in October 2010, and steel tubular truss erection started on May 15th, as shown in Figure 13. The whole bridge is expected to be completed in June 2015.

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