Scheme design of a 530m CFST arch bridge--the First Yangtze River Bridge in Hejiang, Sichuan, China

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ABSTRACT : The first Yangtze River Bridge is located in Rongshan Town, Hejiang, Luzhou City, Sichuan Province, China. After feasibility investigation, preliminary design and technical research in all aspects such as landform and geology, navigation condition, bridge style and economic efficiency, a half-through concrete filled steel tubular arch bridge with a span of 530m has been agreed to be feasible in both the construction technique and cost-efficiency.

1 CONSTRUCTION CONDITIONS

The first Yangtze River, being an important bridge over the Yangtze River, locates in Hejiang of Sichuan Province and is one portion of the Chinese national freeway network.

Figure 1 : Geographical map of the bridge sites

The recommended bridge site is the tectonic erosion hilly topography. The blank slope of the Chongqing side is cliffy and more gentle at the lower river side with sandstone blocks. The blank slop of the Yibin side is also cliffy and the landform structure of upper side has a slope with a smaller degree, which forms a valley bank-slope landforms. The two banks have satisfactory geological conditions.

For the recommended bridge site, the intensity degree of a earthquake with a occurrence probability larger than 10% in the next 50 years is 5.5, the maximal horizontal acceleration of the base lock is 32 cm/s^2, and the dynamic acceleration value for earthquake is 0.05g.The intensity degree of the basic earthquake is level Ⅴ.

The grade of the waterway standard for the water course is level Ⅲ. The flood level of a-twenty-year return period for the two sites are 220.60m and 219.70m, respectively. On the other hand, the normal water level of the Zhuyang Stream hydro-junction under construction, which is about 30.2 km away from the recommended site, is 228.38m.This value is higher than value of a-twenty-year return period flood level, so the value of normal water level of the Zhuyang Stream hydro-junction is considered as the maximal elevation of the navigable water level.

2 BRIDGE SITE AND SPANS

2.1 bridge site

According to the technical requirement of the bridge site demonstration, detailed analysis of upper and lower bridge sites has been done in the preliminary design stage, as shown in Fig.2.

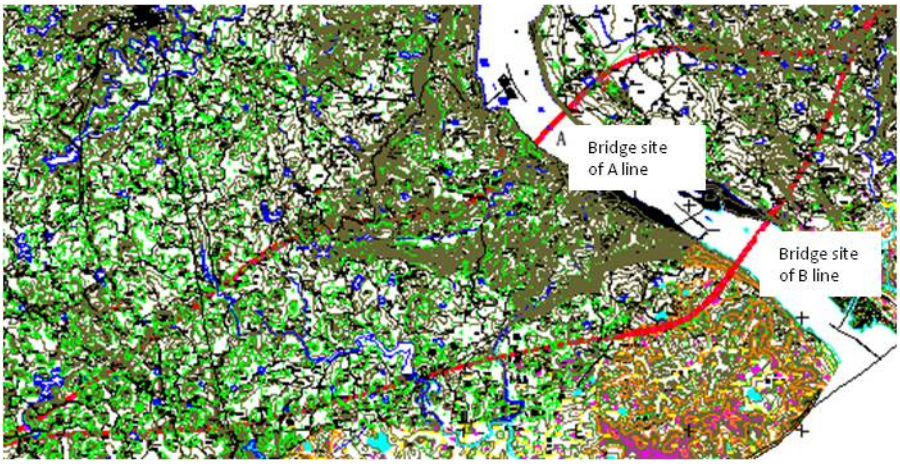

Figure 2 : Layout diagram for bridge sites A and B

The lower site (A), about 6 km away from the Hejiang county town, crosses the Yangtze River nearby Chaqi Kiosk of Wenqiao village of Rongshan Town. For the upper site (B), about 4 km away from Hejiang county town , crosses the Yangtze River nearby Liushuiyan.

Table 1 : Technical comparisons of different bridge sites

bridge site	Lower site(line A, recommend)	Upper site(line B, comparison)
stream and riverbed condition	steady	riverbed is steady but stream is of poor flow pattern
Landform-geology condition	better	good
Navigation condition	good	bad
Consistence with general trend	better	good
Length of main bridge(m)	518	684
Total length(m)	838	1098
Operation mileage	shorter	longer
Cost(billion yuan)	0.25	0.376

The date in Table 1 showed that the lower site (line A) has obvious advantages compared to the upper one (Line B). Therefore the lower site (Line A) was considered as the recommend site.

2.2 Bridge spans

Because of the construction of the Zhuyang Stream hydro-junction project, the highest navigation water lever is controlled by its planned water lever (about 8m above the highest natural navigation water lever). According to the "golden waterway planning" requirement of the Yangtze River and the terrain condition of the bridge site, accrediting experts as well as the administration and transportation apartments of the Yangtze River Waterway considered that the proposal given by the Navigation Demonstration Department is reasonable.

Considering various factors such as the landform condition, the anti-collision installing, the endurance, the geology protection, the construction cost of an arch bridge with a span of 530m would be the most cost-efficient solution. It is because that :

(1) The anti-collision installing as well as their maintenances is much easier to dealt with than that in a steel suspension bridge;

(2) The outsourcing reinforced concrete section is not required duo to the baring of the arch spring, and the construction period is shorten with the decrease of the cost compared to concrete

arch bridge;

(3) The horizontal distance between the arch spring and the free face of the bed rock is moderate. Hence no measurements are needed for the free bank for an arch bridge;

(4) The navigation clearance meets the requirement of the Transportation Department.

3 BRIDGE STYLE DEMONSTRATIONS

Based on the analysis of terrain and geology for the bridge site, three schemes can be adopted including a single span suspension bridge with a main span of 520m, a half-through steel-boxed arch bridge with a main span of 500m, and a half-through CFST arch bridge with a span of 530m. Comparisons of them with a same grade in accuracy are shown as follows.

3.1 Scheme 1: a single span suspension bridge with a main span of 520m

This scheme proposes a single span suspension bridge having a total length of 810m, with a span arrangement of 10×20+520+4×20m, as shown in Fig.3. A simply supported system having a main span of 520m and a rise-to span ration of 1/10 is adopted for the main bridge. Besides, two reinforced concrete cable towers, girders consisting of truss with shaped steel stiffening and the reinforced concrete decks, and the main cables with parallel wires are all the main structure components of the bridge.

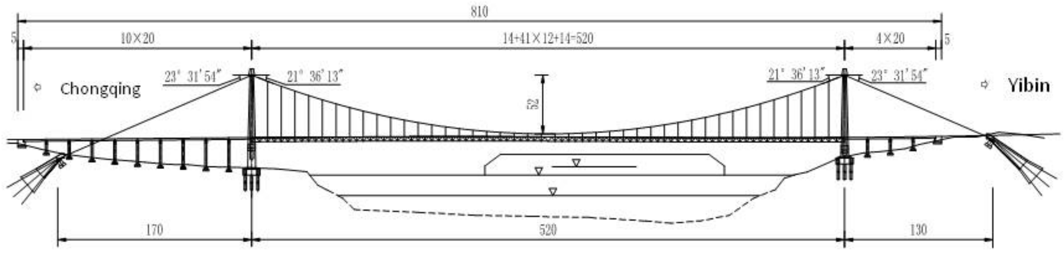

Figure 3 : General layout of the suspension bridge of scheme 1

3.2 Scheme 2 : a half-through stee -box arch bridge with a main span of 500m

The arrangement for the second scheme is a 30-m PC simply supported bridge with T shaped girders plus a 500m half-through steel-boxed arch bridge and 6×30m PC simply supported bridge with T shaped beams. The total length of the bridge is 750m, as shown in Fig.4.

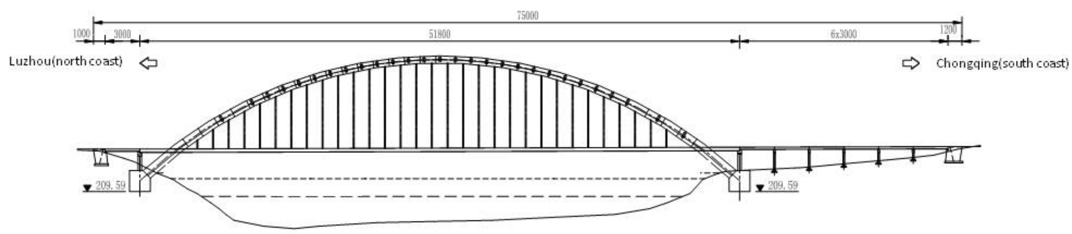

Figure 4 : General layout of the steel-boxed arch bridge of scheme 2

3.3 Scheme 3 : a half-through CFST arch bridge with a main span of 530m

The third scheme is a CFST arch bridge with a span arrangement of 11×20m (the bridge approach)＋530m (the main bridge)＋5×20m (the bridge approach).The general layout is illustrated in Fig.5. A prestressed RC boxed girder with flanges is adopted as the bridge approach. The main bridge is a half-through CFST arch bridge with a clean span of 500m, comprising a I-shaped grillage deck beam and a steel-concrete composited bridge deck. The distance between each suspender is 14m and the length of bridge approach and the whole bridge are 320m and 841m, respectively.

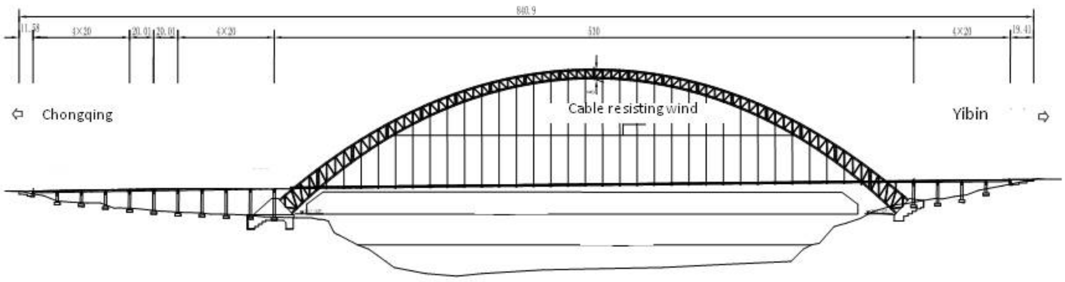

Figure 5 : General layout of the CFST arch bridge of scheme 3

3.4 Technical and Economical Comparisons of three bridge schemes

Table 2 shows the technical and economical comparisons of the three bridge schemes. The comparison results demonstrate that the CFST arch bridge with a span of 530m has the lowest construction cost and more artistic appearance with low cost of maintenance. Therefore, such bridge type is suggested as the solution, i.e., CFST arch bridge.

Table 2 : Technical and economical comparisons of the three bridge schemes

Bridge type scheme	Scheme 1（suspension bridge）	Scheme 2（steel box arch bridge）	Scheme 3（concrete filled steel tubal arch bridge ）
Overall length	810m	750m	841
Main span	520m	518m	530
Approach span	280m	290m	311
High strength steel	3304 ton	148 ton	724
Ordinary steel	9455ton	23694 ton	12441
Concrete	43344m^3	29400m^3	37900
Costs	310.57million	493.83 million	250.30 million
Merits and drawbacks	Merits: concision and lightness, reasonable span, mature construction process, low cost. Drawbacks: using vast high strength steel, higher cost in repair and maintenance.	Merits: full of power and grandeur, artistic appearance, landscaping. Drawbacks: using lots of steel, higher cost in repair and maintenance, difficult construction, high cost.	Merits: type suit to terrain and geology, beautiful build, shorter project time, low construction cost. Drawbacks: more complex construction procedures.

4 TECHNICAL FEASIBILITY

By the statistics, more than 230 CFST arch bridges have been built in China, 3 of which have spans longer than 400m and the longest one is the Wushan Yangtze River Bridge with a maximum span of 460m. There are 2 CFST suspension bridges with a longest span of 560m, 2 CFST continuous rigid frame bridges with a longest span of 120m, more than 10 CFST bridge piers with a maximum height of 183m. As the fastest development of bridge types in the domestic bridge structural system, representative CFST bridges at each period are showed in table 3.

Table 3 : Rain representative bridges at each period

	
The Wangchang East River Bridge in Sichuan with a span of 115m, built in 1980	The Nanhai Sanshanxi Bridge in Guangdong with a span of 200m, built in 1995
	
The Yajisha Bridge in Guangdong with a span of 360m, built in 2000	The Wushan Yangtze River Bridge in Chongqing with a span of 460m, built in 2005

According to the requirements of Chinese CFST constructive technology, numerous experiments have been carried out and some research findings are shown in table 4.

At the same time, relying on the design of this bridge, some research has been carried out to enhance the quality of CFST arch bridges. The research includes 1) steel-concrete composite structure with orthotropic plate deck; 2) the pouring quality of CFST; 3) the influence of temperature on the stress redistribution of CFST and 4) the stabilization and dynamic behaviors of super-long span arch bridges. In terms of the known research results, the Guide of Design and Construction Technology of Road Steel Tube Concrete Bridges, compiled by the Highway Planning and Prospective Design Academy of Transportation Department of Sichuan Province, was published in August 2008. This Guide plays an important role in the design and construction technology of the bridge in this study.

5 DIFFICULTY EVALUATIONS

Compared with the Wushan Yangtze River Bridge of 460m opened to traffic in 2005, two indices are utilized to evaluate the difficulty in constructing the CFST arch bridge having a 530m span. They are two parts of the qualification and construction conditions.

Table 4 : Some key research projects

Number	Name of research projects	Source of research	Time of checking
1	Research on fatigue test of CFST welded truss nodes	Subsidize with project	April 1995
2	Experimental research of chemical self-stressing CFST in bridge engineering	Ministry of Communications in Sichuan Province	March 2008
3	Research on fabrication technique of high expansive concrete of large span CFST arch bridge	Ministry of Communications in Sichuan Province	April 2005
4	Research on optical fiber monitor system of large scale CFST arch bridge	Western Research Center	December 2004
5	Research on the influence of debonding on the structural behavior of concrete-filled steel tube	Ministry of Communications in Sichuan Province	December 2008
6	Key issues of design theory on CFST arch bridge	Ministry of Science and Technology in Fujian Province	May 2004
7	Research on the behavior of transferring force for compressive CFST	Research project at own expense	December 2008
8	Research on wind-resistance behavior of CFST	Research project at own expense	ongoing
9	Research on lateral stability of CFST arch bridge	Research project at own expense	April 2008
10	Research on complete technique of Wushan Yangtze River Bridge designed	Ministry of Communications in Sichuan Province	October 2005
11	Research on crucial technique of design, construction and maintain of CFST arch bridge	Western Research Center	December 2007
12	Experimental research on the application of steel-concrete composite structure in bridge engineering	Science and Technology Department of the Construction Ministry	October 2007

5.1 Design qualification

It can be seen from Table 5 that:

(1) The span of the Hejiang Yangtze River Bridge is 70m longer than the Wushan Bridge and the arch rise is 10m lower, which overcomes the difficulty in pouring concrete with increasing spans;

(2) It properly decreases the hoisting difficulty by decreasing the span of hoisting, though 600 kN of hoisting weigh is heavier than that in Wushan Bridge;

(3) The deck slab span is 9m wider, but the deck slab weight decreases 42 kN/m^2 by adopting the steel-concrete composite orthogonal bridge deck;

(4) Compared with the Wushan Bridge, the entire span of the Hejiang Yangtze River Bridge is longer including 1～2m higher main arch, 100 millimeters larger steel diameter and 42 kN/m lighter bridge deck. Therefore, compared with the Wushan Bridge, the structural safety coefficient of the Hejiang Yangtze River Bridge improves 11.7%.

Table 5 : Comparison of aggregative qualifications

Index	Height of arch section（m）	Diameter of main tube (mm)	Arch rise (m)	Maximum hoisting height (KN)	Hoisting span (m)	Bridge width (m)	Deck slab weight（KN/m）
Hejiang Bridge	8～16	1320	111	190	550	28	242
Wushan Bridge	7～14	1220	121	118	576	19	284

5.2 Construction conditions

In terms of the environment of two bridges, their own construction conditions are compared as follows:

(1) Due to the good geology and high bearing capacity of ground, it is suitable for building arch bridges;

(2) The bridge is over Yangtze River and the transportation is convenient;

(3) There are professional millwork plants for fabricating and transporting steel structure in Luzhou and Chongqing which are respectively located in upstream and downstream of the bridge site, which provide convenient condition for manufacture of the steel structures;

(4) Owing to the low design wind speed and slow water flow rate, it is propitious to the hoisting and erecting of segments.

The bridge has been designed as a CFST arch bridge with a span of 530m and constructed in 2009.

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