LONG SPAN ARCH BRIDGES IN CHINA

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Key words: Arch bridge, steel, concrete, concrete filled steel tube, construction, China

Abstract: *Arch bridge is one of the main bridge types in China. More than 150 concrete arch bridges and more than 130 CFST arch bridges with a span over 100m have been built. Great developments of arch bridges have been taking place since 1990. The three main kind arch bridges with world span records were built in this period, i.e., 550m Lu Pu Bridge for steel arch bridge, 420m Wanxian Yangtze River Bridge for reinforced concrete arch bridge and 460m Wu-shan Yangtze River Bridge for concrete filled steel tubular arch bridge. Arch bridge is still developing. This paper briefly presents an overview of the achievements in arch bridge in China since 1990.*

1. INTRODUCTION

Arch bridge is one of the main types of bridge in the field of civil engineering. The history of arch bridges can be traced back to before the Christian era. In China, ancient arch bridges have achieved high prestige in the world, such as the Chaw-Zhou Bridge, completed in 605 A.D, with a span of 37.4m. Stone arch bridges dominated the development of ancient bridges in China, and it still occupies an important place in the domain of modern bridges.

Since 1960s, many RC arch bridges have been built in China. The statistics shows that around 70% of highway bridges are arch bridges until 1990s (H. F. Xiang 1993). Among these arch bridges, most of them are stone and reinforced concrete arches. Because labor, material of stone and concrete are cheaper, stone or reinforced concrete arch bridges were economic to be built for a long time until 1980s.

In 1960s and 1970s, many concrete arch bridges with light self-weight were presented and applied, in order to save materials, lighten the substructure and foundation, made erection easy. These bridges include curvature arch bridge, rigid-framed arch bridge, trussed arch bridge and prestressed trussed arch bridge.

From 1980, thank to the development of economic, many arch bridges with reinforced concrete box rings and ribs have been constructed. Most of them are deck fixed arch with RC spandrel columns and simple deck girders. Accompanied with the developing of erection technologies such as the horizontal swing method, the embedded scaffolding methods, the span record was refreshed continually. Till 1990, the typical concrete arch bridges built in China are as follows: the Mamingxi Bridge erected by cantilever method with a span of 150m and completed in 1979; the Baoding Bridge with a main span of 170m built by steel scaffolding in 1982; the Fuling Bridge with a main span of 200m erected by horizontal swing method which was completed in 1989; and the Yibin Xiaonanmen Bridge with a main span of 240m built by embedded shaped steel scaffolding at the next year.

In 1990，the first Concrete filled steel tubular (CFST) arch bridge was built in China. It is the Wangcang Donghe Bridge, a through tied rigid-frame arch bridge with a span of 115m, dumbbell arch ribs erected by cantilever method.

CFST arches surpass steel tubular arches and reinforced concrete arches in many aspects. The in-filled concrete delays local buckling of the steel tube. The steel tube reinforces the concrete to resist tension stresses and improve its compression strength and ductility. Moreover, in construction, the tube also acts as a formwork for the concrete. Besides, they present a more artistic appearance. With the rapid development of economy in China, CFST arch bridges become a good alternative to RC arch bridges or steel arch bridges and more than 200 of them have been built.

In 1995, Nanhai Sanshanxi Bridge in Guangdong with a main span of 200m was completed, which is the first fly-bird-type CFST arch bridge and the first one with a span to 200m. In 2000, Yajisha Bridge in Guangdong with a main span of 360m was open to traffic (Figure 13), which was erected by combining vertical and horizontal swing method and held the span record at that time (B. C. Chen 2005). In 2005, the Wushan Yangtze River Bridge with a span of 460m was completed (Figure 12), which is the largest one at present. Currently, there are still some large CFST arch bridges are under construction, such as Taipinghu Bridge and Zhijinghe Bridge. The Taipinghu Bridge, located in Anhui Province,

is a lifting-basket half-through CFST arch bridge with a main span of 336m. The Zhijinghe Bridge in Hubei Province is a deck CFST arch bridge with a main span of 430m.
CFST members are not only served as arch ribs in China, but also are taken as embedded scaffolding to construct concrete arch bridges. It makes the embedded scaffolding method very economic and the span of concrete arch bridge can reach longer.
In 1996, Yong-jiang Bridge with a main span of 312m was completed, using CFST arch as embedded scaffolding. In construction, the steel tubular truss arch was erected by cantilever method and concrete was filled into steel tubular chords after its closure to form a CFST arch. Then concreting was carried out to form the two box ribs by means of a cable crane (J.Y. Wang et al. 2004).
The present world record for the span of concrete arch bridge--the Wanxian Yangtze River Bridge was also constructed by this method, which is a deck box ring arch bridge with a clear span of 420m and deck width of 24m. The main arch rib is a three-cell rectangular box, 7m high and 16m wide. It was completed in 1997 (G. M. Yan and Z. Yang 1997).
Steel is a material with superior strength and ductility, so it is possible to make the span of arch bridge longer. In China, for a long period, steel products per person were very small; so few steel arch bridges have been built before 2000. On June 28, 2003, the Lu Pu Bridge was open to traffic. This bridge in Shanghai with a main span of 550m, crossing the Huangpu River, is the longest span of arch bridge in the world. In recent years, some steel arch bridges with large spans are under construction or planning in China, such as the Xinguang Bridge in Guangzhou, Caiyuanba Bridge and Wangjiatuo Bridge in Chongqing. However, stiffness required for steel arch bridges consumes more steel and causes difficulty in fabrication or erection, compared with girder-typed bridges or cable-stayed bridges. Therefore, steel arch bridges are generally expensive than other bridges and it is not reasonable to built too many long span steel arch bridges.
At present, China keeps all the span records of stone arch bridge (New Danhe Bridge, 146m), steel arch bridge (Lu Pu Bridge, 550m), reinforced concrete arch bridge (Wanxian Yangtze River Bridge, 420m) and concrete filled steel tubular arch bridge (Wu-shan Yangtze River Bridge, 460m) (Chen 2005). Arch bridge is still developing. This paper briefly presents an overview of the achievements in arch bridge in China since 1990.

2. STEEL ARCH BRIDGES

In China, for a long period, steel products per person were very small; so few steel arch bridges have been built, in which most of them are combined trussed (or beam) arch bridges. Jiujiang Yantze River Bridge in Jiangxi Province is a bridge of steel truss strengthens by arch with a main span of 216m. The bridge carries double deck for 4 lanes highway in upper deck and double track railway in lower deck. It was completed in 1992.
Lu Pu Bridge in Shanghai with a main span of 550m, crossing the Huangpu River, is the longest span of arch bridge in the world, 32m longer than the 518m-long New River Gorge Bridge, West Virginia, United States (Figure1).
The span arrangement of Lu Pu Bridge is 100+550+100m. The arch rise is 100m and the rise to span ratio is 1/5.5. Each of the twin steel box arch ribs has a width of 5.0m and a depth of 6m at crown and 9m at the arch spring. The arch ribs are connected with both 25 straight bracings above the deck and 8 K-shaped bracings bellow the deck. Horizontal

cables are adopted to balance the horizontal force of the arch. 28 pairs of hangers are used to link the bridge deck to the arch ribs (Y.P. Lin etc, 2004).

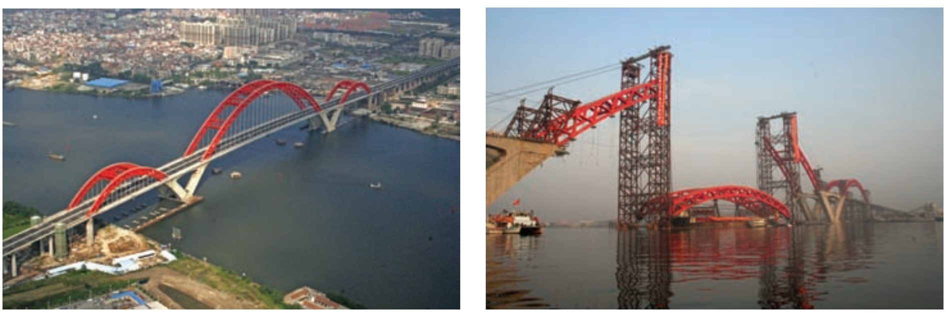
Construction of the huge six-lane Lu Pu Bridge began on October 2000 and completed on June, 2003. The main section of the 3,900m-long bridge is 750 meters long and 28.7m wide. Half of a box arch rib was divided into 27 segments, cantilevered out and tied back to temporary steel towers by cables, as shown in Figure 1(b). Over 35,000 tons of steel has been used in its construction.

(a) Finished (b) Under construction

Figure 1: Lu Pu Bridge in Shanghai

Encouraged by Lu Pu Bridge, some steel arch bridges with large spans have been proposed. Two completed bridges, Xinguang Bridge and Caiyuanba Yantze River Bridge, will be introduced here.

Xinguang Bridge, located in Guangzhou, is composed of two PC triangle frames and three steel arches, as shown in Figure 2. The steel arch ribs are truss with box sections. The central span is 428m and the two side-span are respectively 175m. After the triangle prestressed concrete piers completed, each span steel arch ribs were hoisted by three segments. It was completed in 2006.



(a) Finished (b) Under construction

Figure 2: Xinguang Bridge in Guangzhou

Caiyuanba Yantze River Bridge (Figure 3), located in Chongqing, was opened to traffic at 29 October, 2007. The main span is 420m and two side spans are 102m long. It is a bridge with double decks. The upper deck carries six lanes of highway and two pedestrian walkways and the lower deck carries two tracks of monorails. The arch ribs are erected sing the high lines and a temporary cable-stayed system with its pylons located above the main piers (M. C. Tang and J. Sun, 2004).

(a) Imaged view (b) Under construction

Figure 3: Caiyuanba Yantze River Bridge in Chongqing

Chaotianmen Bridge (Figure 4) is another long span steel arch bridge under construction in China today. It is also located in Chongqing. It will be 1,741 meters long, and has only two major piers in the Yangtze River. The main arch is shaped like a semicircle with a span of 552 meters and is the longest in the world. The main truss arch ribs were closed in January 25th, 2008.

(a) Imaged view (b) under construction

Figure 4: Chaotianmen Yantze River Bridge in Chongqing

Steel is a material with superior strength and ductility, so it is possible to make the span of arch bridge longer. However, stiffness required for steel arch bridges consumes more steel and causes difficulty in fabrication or erection, compared with girder-typed bridges or cable-stayed bridges. This is one of the reasons why only a few steel arch bridges have been built since 1970s in the world. Because China is a developing country, the labor power is cheap and the steel material is relatively expensive, so steel arch bridges are much more expensive than the other types of bridges. Therefore, though there are some large steel arch bridges are built in China in recent years, but in the author’s point view, it is unseasonable to build too many large steel arch bridges in China at present.

3. REINFORCED CONCRETE ARCH BRIDGES

3.1 Structural forms

An investigation shows that there are 151 concrete arch bridges with spans equal to or longer than 100m in China were built or under construction until March, 2006. Furthermore, 53 of them have a span equal to or longer than 150m (B. C. Chen 2007). Figure 5 shows the variance of span in concrete arch brides in China. From the figure it is possible to understand that for span from 100m to 179m, there are 137 bridges, accounted for about 91% of the investigated bridges. Concrete arch bridge with a span under 180m is not difficult to construct and can meet the requirement of economy, especially in mountainous area. In addition, approximately 9% are bridges with span of 180m -199m and 5% equal to or longer than 200m.

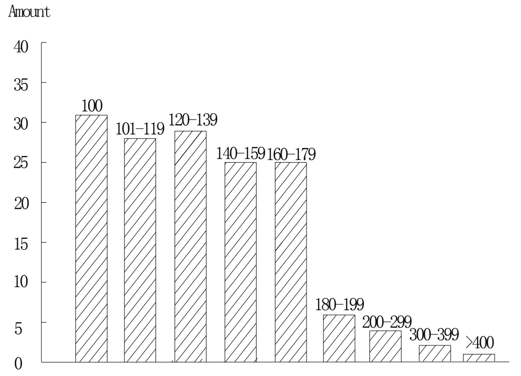


Figure 5: Variance of span of concrete arch bridges in China

The concrete arch bridges in China can be classified into three main forms, which are deck (true) arch, light deck arch, half-through arch, as well as other form. Table 1 lists the forms of the investigated bridges.

Structure form		Amount		Percentage	
	Box ring	50		38	
	Ribbed	12		9	
Half-through		16		12	
	Double-curved	13		10	
	Rigid-frame	5		4	
	Truss	32		25	
Others		3		2	
Total		131		100	

Table 1: Concrete arch bridge forms

It is indicated from Table 1 that 62 of them are deck (true) arch bridges, accounted for 47%. Therefore, this form is the most popular form in long span concrete arch bridges. Only 16 (accounted for 12%) of them are half-through arch bridges, however some of them have long spans, such as the Yong-jiang Bridge (Figure 8). In deck and half-through arch bridges, most of the arch cross-sections are box rings or box ribs for its excellent rigidity and capacity of resisting bending, especially in long span bridges. According to our investigation, there are 58 bridges of them adopted box cross sections, accounted for 80% of the 71 bridges knowing cross-section.

Light arch bridges are special form bridges have been built in China. This form bridges account 39% of the total (50 bridges out of 131). They are economic and saving cement and steel, so can meet the requirement to build a lot bridges with shortage of construction materials supply during the Cultural Revolution. However, with low design load standard, deficient load capacity, small bridge width, these bridges can not satisfy the increasing traffic demand at present. Moreover, these bridges have inherited insufficiency of integrity, load carrying capacity and cracks are apt to appear in the web joints in double-curved arch rings and rigid joints of the truss arch bridges. Many of them have been removed and rebuilt. Fewer such new bridges were built after 1980. But there are still a great deal of them in service in substandard in one way or another with different extend, therefore, overall inspection, rehabilitation and strengthening for these light concrete arch bridges are serious in China.

3.2 Construction methods

Construction methods used in concrete arch bridges in China can be classified into four types, i.e., scaffolding, embedded scaffolding, cantilever method and swing method. There were 13 bridges used classical scaffolding method, most of them built in 1960s and 1970s. It is most suitable for the small span bridges, especially when it crosses non-navigable river. In China, most of the scaffoldings are made of timbers; only few of them used steels, such as Baoding Bridge with a main span of 170m and Xuguo Bridge with a span of 220m.

Currently, the most widely adopted construction method in concrete arch bridge is cantilever method. Among 87 bridges, 52 of them adopted this method, accounted for 60% of the total; in particular, the entire light arch bridges built during 1960s to 1980s adopted this method.

Cantilever method can be further divided into cable-stayed and cantilever truss method. In China, cantilever truss method was only used in the prestressed truss concrete arch bridges. The cable-stayed method is mostly widely used in China. In this method, the arch ribs are prefabricated in segments and hoisted by cable crane, so it is also called cable crane method or cantilever assembling method. However, limited by the hoisting capacity of the cable crane, this method is only adopted in arch bridges with a span smaller than 200m. Modong Bridge in Guangxi with a main span of 180m and a rise-to- span ratio of 1/6, was constructed by this method, as shown in Figure 6.

(a) Finished (b) Under construction

Figure 6: Modong Bridge in Guangxi

Swing method consists of building two half bridges, which are then rotated vertically or horizontally on temporary pivots to closure. The horizontal swing method has been used in various bridges, such as cable-stayed and T-rigid frame bridges. However, only in China it is used in arch bridges. From 1975, research on horizontal swing technique in construction of concrete arch bridge was carried out and it was successfully applied in Shining Bridge in 1977, which is 70m span box ribbed reinforced concrete arch bridge. The fabricated semi-arch and the counterweight abutment on the rotation disk were rotated horizontally around a pivot and a preinstalled Teflon ring-like slide to closure position. However, this method is limited by the self-weight of concrete arch ribs when the span is larger. Therefore, a swing system without balance weight was developed. After successfully applied in Longmen Bridge, it was employed in the Fuling Bridge with a main span of 200m in 1989 (Figure 7). The three-cell box ring was divided into three parts in construction. The two side cells were erected by horizontal swing method without balance weight. In this method, only the arch ribs on the pivot were rotated to closure. Then two box ribs were connected by casting in-situ to form the middle cell (L. Y. Zhang and J. Chen 2004).

(a) Finished (b) Under construction

Figure 7: Fuling Bridge in Sichuan

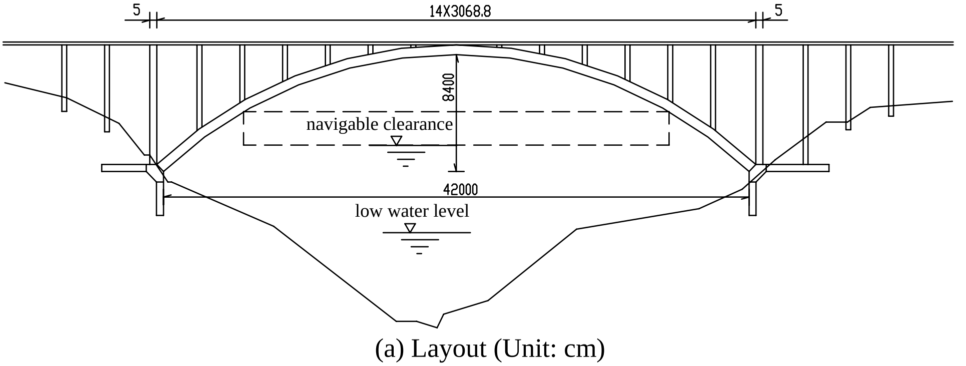
Embedded scaffolding method is another main construction method. In 1980s, in order to reduce the steel assumption, scaffoldings without enough stiffness were employed and many control methods were presented, such as the method using the weight of water tanks hanging in the scaffolding as a balance when concreting, adjustment of internal forces of fastening cable tied to the scaffolding. However, the geometric form of the arches was not easy to control. Thanks to CFST member applied in the embedded scaffoldings, many long span concrete arch bridges have been built in China in recent years.

Yongjiang Bridge, located in Yongning, Guangxi Province, China, is a reinforced concrete arch bridge with a main span of 312m (Figure 8). The arch ribs were cast in site by means of embedded scaffolding method. The scaffolding (steel arch ribs) are composed of four steel tubular chords and shaped steel members, which were erected by cantilever assembling method with cable crane. In erection of the steel arch ribs and casting the concrete of the ribs after the enclosure of the steel tubular arch ribs, which were suspended and their axis shapes were adjusted by cables pulling with jacks (J. Y. Wang et al. 2004).

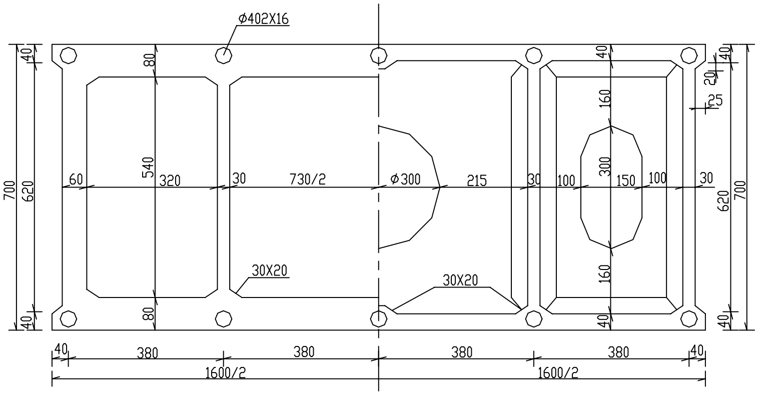
(a) Finished (b) Cross-section of box rib

Figure 8: Yongjiang Bridge in Guangxi

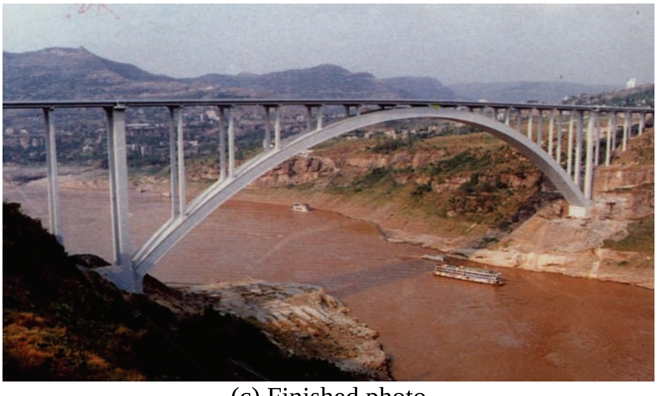
Similar to Yong-jiang Bridge, CFST skeleton was also used in Wanxian Yangtze River Bridge, which is a RC arch bridge with a clear span of 420m and deck width of 24m (Figure9). The main arch rib is a three-cell rectangular box, 7m height and 16m wide. The stiffened skeleton is composed of a truss CFST arch and shaped steel bar, the chord bars are steel tubes of 402mm 16mm filled with C60 concrete. Wanxian Yangtze River Bridge was completed in 1997 and it is the largest span concrete arch bridge in the world (G. Yan and Z. Yang 1999).



(a) Layout (Unit: cm)



(b) Cross-section of arch ring (Unit: cm)



(c) Finished photo

Figure 9: Wanxian Yangtze River Bridge in Sichuan

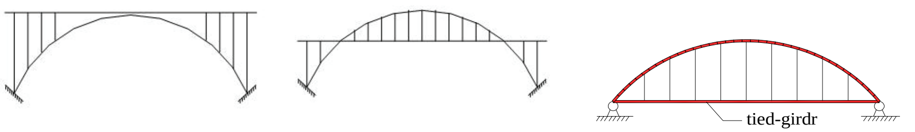
Because large span concrete arch bridge is not easy to be erected, so if the arch bridge span is over 300m, steel or CFST arch bridges will be considered to replace the reinforced concrete arch bridges at present. Therefore, there are few large-span RC arch bridges to be built and less research carrying on large-span RC arch bridge in China these days. However, in the mountain area, when bridges cross over V-shaped or U-shaped valleys, concrete arch bridges are still suitable and economic to be used with spans not longer than 180m. For larger span, research should be carried out on the new structure type, high strength and light materials and the erection methods.

4. CONCRETE FILLED STEEL TUBULAR ARCH BRIDGES

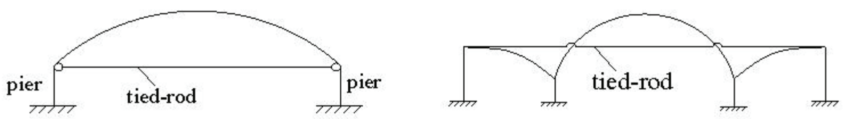
4.1 Structural forms

Concrete Filled Steel Tubes (CFST) arches surpass steel tubular arches and reinforced concrete arches. The in-filled concrete delays local buckling of the steel tube. The steel tube reinforces the concrete to resist tension stresses and improve its compression strength and ductility. Moreover, in construction, the tube also acts as a formwork for the concrete. With the rapid development of economy in China, CFST arch bridges become a good alternative to Reinforced Concrete (RC) arch bridges or steel arch bridges. Besides, they present a more artistic appearance. The first CFST arch bridge in China, Wanchang Bridge, with a main span of 115m, was completed in 1990 (Chen et al. 2004). From then on, numerous CFST bridges have been built. Up to March 2005, 229 CFST arch bridges, with the span over 50m, have been built or are under construction (Chen 2007). Among them, 131 bridges have a main span longer than 100m (B. C. Chen 2007).

CFST arch bridges can be classified into five main types, i.e. deck (true) arch, half-through true arch, through deck-stiffened arch, through rigid-frame tied arch and fly-bird-type arch (half-through tied rigid-frame arch) (Figure 10). It should be noted that for the deck and half-through arch with thrust, the span is clear span; while for no-thrust arch, the span is from the center line of pier to pier.



(a) Deck (true) arch (b) Half-through true arch (c) Through deck-stiffened arch



(d) Through rigid-framed tied arch (e) 'Fly-bird-type' arch

Figure 10: Types of CFST Arch Bridges

The quantity of each type of CFST arch bridges with span greater than 100m is shown in Table 2. From Table 2, it can be seen that the half-through arch and through arch are the main types of CFST bridges in China. By contraries, accounted for 88%, the majority of long-span concrete arch bridges are deck bridges, only 14% are half-through bridges (B. C. Chen 2007).

The spans of CFST arch bridges shown in Figure 11 have been altered since 1990. It can be seen that before 1995 there were few CFST arch bridges of which spans are greater than 100m. From then on, with the advanced analysis and new construction technology, the spans and the quantity of CFST arch bridges have both increased. The following are some typical bridges at different time periods: Wangcang Donghe Bridge, with a span of 115m, was the first one completed in 1990. Nanhai Sanshanxi Bridge, with a span of 200m, was completed in 1995. Yajisha Bridge of 360m span was built in 2000. Up to now, Wushan Yangtze River Bridge, completed in 2005, has been the bridge with the longest span of 460m. Presently, corresponding to the five aforementioned types of CFST arch bridges, the span records are respectively: 288m of Fengjie Meixihe Bridge for deck arch, 460m of Wushan Yangtze River Bridge for half-through arch with thrust, 360m of Yajisha Bridge for ‘Fly-bird-type’ arch, 202m of Moon Island Bridge for through arch of arch-girder combined system, and 280m of No.3 Hanjiang Bridge for through rigid frame tied arch.

Types	Quantity	Percentage (%)
Deck (true) arch	11	8
Half-through (true) arch	62	47
“Fly-bird-type” arch	24	18
Through deck-stiffened arch	18	14
Through rigid frame tied arch	16	13

Table 2: Quantity of each Type of CFST Arches

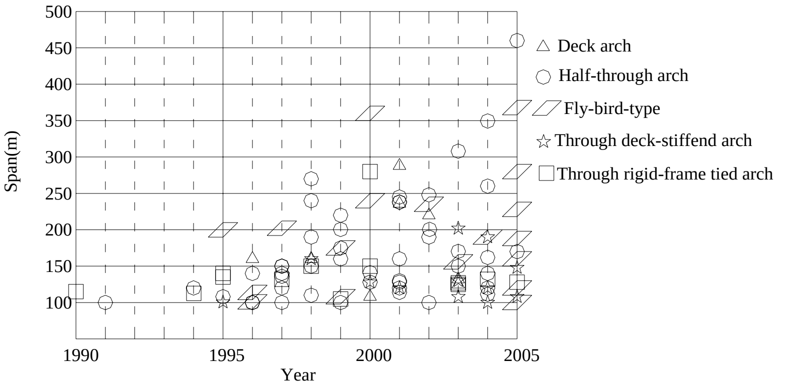


Figure 11: Variance of CFST Arch Span with Time

4.2 Construction methods

Cantilever method, swing method, and scaffolding method are three major erection methods for the construction of CFST arch bridges (B. C. Chen 2007). For those bridges which the construction method is known, the quantity of CFST arch bridges built by different erection methods is shown in Table 3.

Bridge Types	Construction Methods				Total
	Cantilever Method	Swing Method	Scaffolding Method	Others	
Deck (true) arch	5	3	1	1	10
Half-through (true) arch	39	4	3		46
“Fly-bird-type” arch	12	4	3		19
Through deck-stiffened arch	4	2	6	1	13
Through rigid frame tied arch	9	2	3	1	15
Total	69	15	16	3	103

Table 3: Quantity of CFST Arch Bridges based on different Construction Methods

In construction of a CFST arch bridge, the steel tubular arch is erected at first and then concrete is pumped into steel tubes to form CFST arch ribs. Though the thin-walled steel tubular arch has a lighter self-weight than concrete or shaped steel arch rib, it is still a key issue in construction when the span is longer. The popular erection methods used in CFST arch bridges are cantilever assembling method and swing method as used in concrete arch bridges. However, these two construction methods have been improved with the development of CFST arch bridges.

In cantilever method, both main and auxiliary cables are used to maintain stability and balance during construction. These cables are stayed and controlled by jacks instead of windlass at past. Therefore, the alignment of arch ring can be controlled by the adjustment of internal force of the fasten cables more easily than before. This method was adopted by 67% of the bridges. In the 8 bridges with a span no less than 300m, there are 7 used this method, including the world's largest one, the Wushan Yangtze River Bridge with a span 460m, as shown in Figure 12 (T. Mu et al. 2007). It is evident that cantilever method is the most potential one in construction of CFST arch bridges for its wide range of application, especially for long span bridges.

(a) Finished (b) Under construction

Figure 12: Wushan Yangtze River Bridge in Chongqing

Another main erection method used in CFST arch bridges is swing method, which has been rapidly developed in recent years in China. This method includes vertical swing method and horizontal swing method. It is more suitable in some special conditions, such as gorge, or high requirements for clearance. Therefore, an appropriate landform and structural configuration are necessary for this method. Swing method is not used as prevalently as cantilever method. Statistics shows that there are about 15% adopted this construction procedure.

In vertical swing method, the semi-arch ribs are fabricated in low position and hoisted up into design level. This is difference as in other countries to build half-arches on the springs vertical and then rotate down on their lower end to close at the crown (Leonardo Fernández Troyano，2004). This up-lift vertical swing method is mainly used in CFST arch bridge for the tubular structure is much lighter than concrete arch ribs. Among those investigated bridges, Liantuo Bridge, Jing-hang Canal Bridge, and Wuzhou Guijiang Bridge are constructed by vertical swing method.

The first two CFST arch bridges constructed by horizontal swing method are the Huangbaihe Bridge and Xialaoxi Bridge near the Three Gorge Dam (Duan et al. 2001). The

first CFST arch bridge in railway-- Beipanjiang Railway Bridge opened in 2001 was also constructed by this method. Adopting jakes pushing system as the drawing power, the rotated capacity in swing method is much greater than that by using windlass pulling system as before in concrete arch bridges. And the arch span can be much longer because steel tubular arch rib is much lighter than that of concrete arch.
A new method by combining vertical and horizontal swing method has been developed in CFST arch bridges, such as the fly-bird-type CFST arch bridge--Wenfenglu Bridge and Yajisha Bridge. For Yajisha Bridge, as shown in Figure 13, the half arch of the main span and cantilever half arch near it composed a rotation unit. First, the cantilever half arch was erected and main half arch was fabricated along the riverbank. Then, the main half arch was rotated vertically into right position. After that, the two half-arches were rotated horizontally, one 90° and the other about 117°. Finally, the arch rib was closed by a 1m long rib-segment. The total weight of each horizontal rotating body is 136,850kN (L. Y. Zhang and J. Chen 2004.).


(a) Vertical Swing


(b) Horizontal swing


(c) Finished photo

Figure 13: Yajisha Bridge in Guangdong

5. CONCLUSIONS

Stone arch bridges have taken important roles in road systems in history in China. However, it is heavy, labor consuming and difficult to build and is not an economic bridge type to be considered at present in many cases. The maintenance, rehabilitation and strengthening of these stone arch bridges have became a very important topics in China. Bridge management authority and engineers should pay enough attention to these and learn from research results and engineering experience has been carried out in other countries.

Compared with the other types of bridges in China at present, steel arch bridges are still very expensive to be built. Therefore, it is unseasonable to build too many large steel arch bridges in China at present.

Great effort to improve structure and construction techniques of concrete arch bridges has been made and great achievements of this type bridge have obtained by Chinese bridges engineers. In mountain area, when bridges cross over V-shaped or U-shaped valleys, concrete arch bridges are still suitable and economic to be used with spans not longer than 180m. Because the construction difficulty and material consuming increase with the arch span becomes longer, research should be carried out on the new structure type, high strength and light materials and the erection methods in super-large span concrete arch bridge research projects.

CFST arch bridges have been developing quickly since 1990. The code for design and construction techniques of CFST arch bridge will be published soon after. The researches on design theory, construction techniques, structure detail design are hot topics these days and are supported by many funds and engineering projects. These research works will make the design theory and construction techniques of CFST arch bridge progress and more CFST arch bridges be built more reasonably and economically.

REFERENCES

[1] B. C. Chen, 2005. State-of-the-art of the development of arch bridges in China. *Proceedings of the 4th International Conference on New Dimensions of Bridge*:13-24, Fuzhou, China,

[2] B. C. Chen, 2007. An Overview of Concrete and CFST Arch Bridges in China, *Proceedings of the Fifrth International Conference on Arch Bridge:* 38-52 . Madeira, Portugal.

[3] G. Yan and Z. Yang, 1997. Wanxian Yangtze Bridge, *Structural Engineering International*, 1997 (3): 164-166

[4] H. F. Xiang, 1993. *Bridges in China*. Tongji University Press and A&U Publication Co., Shanghai, China

[5] J. Y. Wang, J. Zheng, F. Xu, 2004. Structural Design and Constructin Technology of Yongjian Bridge, Yongning of Guangxi Province, China, *Proceedings of the Fourth International Conference on Arch Bridge*: 723-733.Barcelona, Spain.

[6] L. Y. Zhang and J. Chen, 2004. Application and development of the Rotation Construction Method of Arch Bridges in China. *Proceedings of the Fourth International Conference on Arch Bridge*: 883-888.Barcelona, Spain.

[7] M. C. Tang and J. Sun, Design of the Main Spans of the Chongqing Caiyanba Bridge, *Metropolitan Habitats and Infrastructure--IABSE Symposium, Shanghai 2004, IABSE Reports*: 86-87.

[8] T. Mu, B. Fan, X. Zheng, Y. Zheng and B. Xie, 2007. Wuxia Yangtze River Bridge in Wushan, China, *Proceedings of the Fifrth International Conference on Arch Bridge*: 911-917. Madeira, Portugal.

[9] Y. P. Lin, Z. Zhang, B. Ma and L. Zhou, Lupu Arch Bridge, *Metropolitan Habitats and Infrastructure--IABSE Symposium, Shanghai 2004, IABSE Reports*: 148-159.
[10] Z. Q. Ou, B. C. Chen, 2007, Present Situation and Maintenance of Masonry Arch Bridges in Fujian Province of China, *Proceedings of the Fifth International Conference on Arch Bridge, 12-14, Sept*: 267-274.Madeira, Portugal.