

Jielian Zheng

# Innovative Technology for 500-meter Scale Concrete-Filled Steel Tubular Arch Bridge Construction



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# Foreword

Among the four types of bridges, arch bridge stands out due to its good mechanical performance. To be specific, its arch ring is generally under small eccentric compression, so it is free of fatigue problems. Arch bridge is also characterized by long durability, high stiffness and strong cost competitiveness. Before the Industrial Revolution, arch bridge was the best choice for in-land rivers serving navigation purposes around the world. At that time, arch bridges were constructed upon brackets, which posed high risks in flood control. To this end, Josef Milan, an Austrian engineer, introduced the steel-reinforced concrete (SRC) arch bridge with a stiff skeleton in 1898. Chinese engineers made further improvement on SRC arch bridges by using concrete-filled steel tubular (CFST) arch as the stiff skeleton and ingeniously developed load adjustment techniques, which further led to reduced construction cost and risks of concrete arch bridges. Moreover, the construction of arch ring by a bracket-free technique is another symbol signifying the achievement of modern arch bridges.

Driven by the large-scale construction of highways and railways in China and supported by the bracket-free techniques for arch ring construction, concrete-filled steel tubular (CFST) arch bridges and steel-reinforced concrete (SRC) arch bridges with a stiff skeleton have developed very rapidly. The first CFST arch bridge, the Wangcang East River Bridge with a span of 115 m, was built in 1990. By 2018, more than 460 CFST arch bridges and SRC arch bridges have been built. The Hejiang First Yangtze River Bridge with a span of 530 m has been in operation for 6 years. The Pingnan Third Bridge with a span of 575 m is expected to open to traffic in 2020. It is a rare phenomenon in the history of bridge development that the number and span length of CFST and SRC arch bridges increased so quickly over the past three decades in China.

Technology innovations proposed by Chinese engineers have promoted the fast and healthy development of arch bridges. The cable-stayed fastening and hanging assembly technology developed in 1968 and the arch ring rotation technology proposed in 1977 realized the construction of CFST arch bridges and SRC arch bridges without brackets. Furthermore, in-depth research has also been conducted on the design theories, construction techniques, materials and equipment for these

two types of arch bridges spanning over 500 m, thereby resulting in better quality, lower construction cost and risks.

The author of this book, Zheng Jieliang, an academican of the Chinese Academy of Engineering, has been a witness, participant, and innovator of arch bridges over the past 30 years. In this book, he summarized the experiences and directions of CFST arch bridges and SRC arch bridges. It can be served as a good reference for bridge engineers, researchers and students majoring in bridge engineering. I believe that the publication of this book will contribute to the further development of arch bridges in China.

Shanghai, China  
October 2019

Xiang Haifan

# Authors' Preface

In recent years, there has been a concentrated breakthrough in terms of construction quantity, span, and quality of large-span concrete-filled steel tubular (CFST) arch bridges and steel-reinforced concrete (SRC) arch bridges with a CFST skeleton in China. The breakthrough contributes a lot to China's leading position in arch bridge construction worldwide. As a witness and participant of the long-term development process of arch bridges in China in recent decades, the author wrote this book with the aim of providing a reference for engineers, researchers and college students majoring in bridge engineering. Another aim of this book is to summarize recent successful experiences in China, and then to promote the development of CFST arch bridges and SRC arch bridges with a CFST skeleton toward higher quality, lower cost and risk, and larger span.

The book is divided into 9 chapters, with the main content of each chapter as follows:

Chapter 1 is titled "Introduction". In this chapter, the main characteristics of CFST arch bridges accompanied by their comparison with other types of arch bridges, development history and current level, arch ring erection method, and construction risks are summarized and introduced.

Chapter 2 is titled "Design of 500 Meter-Scale Concrete-Filled Steel Tubular (CFST) Arch Bridges". This chapter mainly introduces the design details of the only three CFST arch bridges in the world that have been completed construction with a main span exceeding 500 m. The comparison results in terms of technology and economy between these three large-span CFST arch bridges and cable-stayed bridges or suspension bridges with the same span are presented. In addition, the innovative suspended segment-based arch ring design method is also highlighted.

Chapter 3 is titled "Arch Truss Segments Fabrication and Transportation". Introductions to the shop manufacturing procedure, shop manufacturing precision control, and ship transportation of the steel arch truss segment of 500 meter-scale CFST arch bridges are presented in this chapter.

Chapter 4 is titled "Design and Construction of Cable-Stayed Buckle System". In this chapter, a brief introduction to the cable-stayed fastening-hanging cantilever assembly system for steel tube arch truss erection of CFST arch bridges is conducted

firstly. And then the design and construction details of the cable-stayed fastening-hanging cantilever assembly system of the Hejiang First Yangtze River Bridge and the Pingnan Third Bridge are illustrated.

Chapter 5 is titled “Methods and Practices of One-Time Tensioning of Buckle Cables”. This chapter focuses on the innovative calculation method of buckle cable force for one-time tensioning of all buckle cables within the cable-stayed fastening-hanging cantilever assembly system. The validation of correctness of this method through several engineering practices is also presented.

Chapter 6 is titled “Preparation and Pouring of In-Tube Concrete”. The contents of this chapter include the innovative technologies and their engineering practices of in-tube concrete with high fluidity, and designable expansion and shrinkage, the vacuum-assisted multi-level pressure method for in-tube pumping.

Chapter 7 is titled “Design, Construction and Application of Cable Hoisting System”. The general information on the suspension lifting system for steel tube arch truss erection as well as the design and construction details of the suspension lifting system of the Hejiang First Yangtze River Bridge (i.e., the Bosideng Bridge) and the Pingnan Third Bridge are introduced in this chapter.

Chapter 8 is titled “Active Force Approach for Displacement Control of Suspension and Buckle Tower”. In this chapter, the control mechanism and the application results of the active force approach for displacement control of suspension and buckle tower are presented.

Chapter 9 is titled “Steel-Reinforced Concrete (SRC) Arch Bridges”. This chapter mainly focuses on the technical innovations and practices conducted by Chinese engineers on the SRC arch bridges. The innovations include the replacement of the traditional steel stiff skeleton with CFST stiff skeleton, the synthetic and systemic methodology to reduce the time-dependent transient stresses of the SRC arch during the encasing concrete pouring as well as the permanent stresses.

The main achievements presented in this book have supported the successful construction of the Hejiang Yangtze River Highway Bridge with a main span of 507 m, the Bosideng Bridge with a main span of 530 m (the world's longest CFST arch bridge in main span), and the Pingnan Third Bridge with a main span of 575 m (the world's longest CFST arch bridge in main span under construction). The first author of this book and his team have participated in and guided the construction of these three bridges. The relevant existing theories and technologies were continuously updated during the construction of these three bridges. Thus, the presented theories and technologies are of high practical application value and guiding significance.

The proofreading and editing work of this book was done by Prof. Zheng Jielian, who is the first author of the book. Prof. Zheng Jielian also independently wrote Chaps. 1, 8 and 9. Chapter 2 was mainly written by Chief Engineer Mou Tingmin of the Sichuan Highway Planning, Survey, Design and Research Institute Ltd., Chap. 3 was mainly written by Chief Engineer Han Yu, Chaps. 4, 5 and 7 by Deputy Chief Engineer Qin Dayan, Chap. 3 by Deputy Chief Engineer Wang Jianjun of Guangxi Road and Bridge Engineering Group Co., Ltd. Other participants in the writing of this book include Xie Weiwei, Zheng Jian, Ye Zhiquan, He Jianqiao, and Kui Leijun from Guangxi Road and Bridge Engineering Group Co., Ltd., Fan Bikun,

Zhao Yicheng, Zheng Xufeng, Lin Xiaojun, Tian Bo, Wang Yang, and Zou Qi from Sichuan Provincial Highway Planning, Survey, Design and Research Institute Ltd. The innovative non-shrinkage in-tube concrete material introduced in Chap. 6 was supported by Prof. Miao Changwen and Prof. Liu Jiaping from Southeast University in China. We would like to express our sincere gratitude to all of them.

Other than those collected by the first author, the images used in this book were supplemented by the construction companies of the bridges mentioned in this book. In addition, the authors would like to thank Deputy Chief Engineer Chen Kejian of the China Railway Eryuan Engineering Group Co., Ltd., the nationally recognized designer Ma Tinglin, the Management Department of the Yunnan-Guangxi Railway Nanpan River Bridge, affiliated with the China Railway 18th Bureau Group Co., Ltd. for providing information of Chap. 9.

Finally, it should be noted that the large-span CFST arch bridges and SRC arch bridges with a CFST stiff skeleton are undergoing a stage of vigorous development as well as widespread promotion and application currently. The span of these two types of arch bridges is also on its way to further breakthrough towards 600 m or even 700 m, and the corresponding construction technologies are constantly innovating and advancing in practical applications. Therefore, the achievements presented in this book are expected to play a role in connecting the past and the future information, and need to be further improved in practice. Therefore, the authors firmly believe that it is needed to write another book on key construction technologies of arch bridges with an even larger span in the near future. In this process, we sincerely hope to receive suggestions, criticisms, and corrections from readers.

Nanning, China  
July 2019

Jielian Zheng

# Translators' Preface

Since the construction of the first modern concrete-filled steel tubular (CFST) arch bridge, the Wangcang East River Bridge, in Sichuan Province, China in 1990, the CFST arch bridge has experienced a continuous rapid development worldwide, especially in China. Due to their outstanding structural, constructional, and economic advantages, nearly 500 CFST arch bridges were built with a maximum span of 560 m within a mere three decades, creating a miracle in the world history of bridge construction. Particularly, over the past ten years, four CFST arch bridges spanning over 500 m were built and another four are currently under construction. CFST arch bridges have now overtaken concrete arch bridges and steel arch bridges to become the longest arch bridges in terms of span. Therefore, two more options with high competitiveness, i.e., CFST arch bridges and steel reinforced concrete (SRC) arch bridges with a CFST skeleton, were added to the candidates for the construction of large-span bridges, along with cable-stayed and suspension bridges.

Under such a background, the Chinese version of this book *Innovative Technology for 500-meter Scale Concrete-Filled Steel Tubular Arch Bridge Construction* was published. Being a witness, participant, and researcher of arch bridges and their construction in China over the past 30 years, the author has led the construction of three CFST arch bridges spanning over 500 m. Based on the technological innovations and practices of the author and his team during the construction of the three large-span arch bridges, the author systematically summarizes the key technologies and innovations accumulated over the past three decades by the Chinese engineers in the design and construction of large-span CFST arch bridges in this book. The book can serve as a reference for bridge engineers, researchers, and students majoring in bridge engineering. The Chinese version of this book has effectively filled the gap in the relevant field and has been widely recognized by readers since its publication in early 2020. Therefore, it was recommended by the Shanghai Science and Technology Press in early 2022 to Springer for publishing in the English version. After one year's translation, the English version of this book was finally published.

The content of the English version of the book is consistent with the Chinese version and is divided into 9 chapters. The translation work was mainly completed by the author's team members as follows. Chapter 1 was translated by Associate Prof.

Tu Bing, Chaps. 3 and 4 by Associate Prof. Yu Peng, Chap. 5 by Dr. Teng Xiaodan, Chaps. 6 and 7 by Prof. Chen Zheng, and Chaps. 8 and 9 by Prof. Yan Banfu. The above translators are all from Guangxi University. Chapter 2 was jointly translated by professor-level senior engineer Wu Hongfeng from Beijing Jianda Road and Bridge Consulting Co., Ltd. and professor-level senior engineer Zheng Chun from CCCC Highway Consultants Co., Ltd. The editing work was done by Prof. Chen Zheng and associate Prof. Tu Bing from Guangxi University. In addition, Associate Prof. Wang Min from Chongqing Jiaotong University, Prof. Liu Fang, Prof. Xie Kaizhong, and Dr. Zhou Xiaohang from Guangxi University have also participated in a large amount of translation work. We would like to express our sincere gratitude to all of them.

Finally, it is worth noting that although CFST arch bridges originated in the former Soviet Union, their large-scale development is within China. The number and span of CFST arch bridges built in China have far exceeded those of other countries. This is partly attributed to the increasing demand for arch bridges brought about by China's large-scale construction of highways and railways in recent decades. The other reason lies in the continuous innovations and breakthroughs in the design and construction of CFST arch bridges made by Chinese engineers. This book aims to showcase part of these achievements. The author hopes to promote the exchange of the "Chinese experience" in the realm of CFST arch bridges worldwide through the publication of the English version of this book and to promote the application of such an excellent bridge type of arch bridge to further benefit all humanity. Due to the limited translation skills of the translators, criticism and correction are kindly requested from the readers of this book.

Nanning, China  
October 2023

Translators

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# Chapter 1

## Introduction



A concrete-filled steel tubular (CFST) arch bridge refers to an arch bridge with a CFST arch or a truss arch with CFST chords. The web member of the truss arch can be section steel or steel tube with or without in-filled concrete. Longitudinally-welded rolled steel tubes with strength grades of Q235, Q345, and Q390 specified by Chinese standard for design of steel structures are generally adopted for the steel tubes [1], and the in-tube concrete generally utilizes concrete with strength grades of C40 ~ C80 specified by Chinese code for highway reinforced concrete and prestressed concrete bridges and culverts [2].

### 1.1 The Characteristics of CFST Arch Bridges

- (1) Compared with steel arch bridges, CFST arch bridges are excellent in mechanical performance, efficient in construction and low in overall construction cost.

A CFST arch bridge can be interpreted as a steel arch bridge with part of the arch ring replaced by the cost-effective concrete. Within a CFST arch ring, the steel tube, together with the in-tube concrete, form a composite structure. The steel tube plays a multifaceted role, functioning not only as longitudinal reinforcement and lateral ties but also serving as the formwork for in-tube concrete pouring. The in-tube concrete is generally continuously poured, which can improve the local stability of the steel tube. On the other hand, the strength and ductility of the in-tube concrete are enhanced by the confinement of the steel tubes. Thus, a CFST arch is an excellent composite structure suitable for compression. Moreover, the CFST arch is mainly subjected to small eccentric compression when rationally designed, thus it possesses good durability and high load-bearing capacity.

The CFST arch bridges also have comparable construction advantages. The weight of the steel tube arch truss of CFST arch bridges is 50% lighter than those of the steel

truss arch bridges, so the erection risk is significantly reduced. The wall thickness of steel tube is also 50% less than that of steel members of steel arch bridges, which makes the welding easier. A single steel tube of CFST arch bridges is lighter than those of steel arch bridges, which is conducive to delivery in mountainous areas. After the steel tube arch truss is installed, the in-tube concrete can be poured using the vacuum-assisted continuous filling method, resulting in a fast in-tube concrete construction within one month for one span. Eventually, the total construction time of a 500-m scale CFST arch bridge, including arch truss installation and in-tube concrete filling, is approximately one-half of the construction time of a steel arch bridge with the same span. Obviously, CFST arch bridges are faster and safer for construction than steel arch bridges.

As presented in Table 1.1, further comparison between a CFST arch bridge and a steel arch bridge, e.g., between the 530 m-span Hejiang First Yangtze River Bridge (i.e., the Bosideng Bridge, a CFST arch bridge) and the 550 m-span Lupu Bridge (a steel arch bridge), indicates that: the amount of steel used on the arch ring and the steel for construction measures of the former is 29% and 36% of the latter respectively. Since the arch ring is generally subjected to compression, part of the arch steel can be replaced by concrete, and more than half of the steel has been replaced nowadays. Considering the current unit price including the material cost and construction cost of concrete and steel are RMB 1000 yuan per cubic meter and RMB 20,000 yuan per ton respectively, the cost ratio of concrete component to steel component with the same sectional stiffness, i.e.,  $A_c E_c = A_s E_s$ , is about 1/27. This result is the source of the quotation in some references that the construction cost of a CFST arch ring is 50% lower than that of a steel arch bridge.

Therefore, when building a thrust arch bridge, the utilization of steel tube concrete arch bridges leads to a swifter construction process, diminished risks, decreased costs, and minimal maintenance requirements. Consequently, steel arch bridges are gradually being supplanted by this more efficient alternative under suitable conditions. For a tied CFST arch bridge, although the quantities of the hangers and abutment foundation construction are slightly higher for a CFST arch bridge, its arch ring weight is only about 1/3 of a steel arch bridge, so CFST arch bridges are also generally more competitive since the total construction cost is lower.

- (2) Compared with cable-stayed bridges, CFST arch bridges possess higher stiffness, stronger terrain adaptability, and better economic benefits.

The arch rings of CFST arch bridges are always under small eccentric compression, resulting in good durability, high load-bearing capacity and large stiffness. To be specific, the stiffness of CFST arch bridges is generally ten times higher than that of cable-stayed bridges and suspension bridges. Furthermore, the stiffness of CFST arch bridges can be further enlarged when necessary, merely by increasing the chord tube diameter and the amount of in-tube concrete. In addition, CFST bridges are adaptable to different kinds of terrain. The plain or hilly areas can adopt the through arch bridges (Fig. 1.1) or half-through arch bridges (Fig. 1.2), while the mountainous areas can adopt the deck arch bridges (Fig. 1.3). Compared with other bridge types, the construction cost of CFST arch bridges can be reduced by up to one-third. Most

**Table 1.1** A comparison between CFST arch bridges and steel arch bridges

| Technical indicators                                     | Steel truss arch       |                          |   | Steel box arch        |   | CFST arch           |
|--|------------------------|--------------------------|---|-----------------------|---|---------------------|
|  | New River Gorge Bridge | Sydney Harbor Bridge     | Chaotianmen Bridge                                | Lupu Bridge           | Bosideng Bridge (engineering feasibility study stage results) | Bosideng Bridge     |
| Main span/m  | 518.1                  | 502.9                    | 552   | 550                   | 518   | 530                 |
| Bridge width/m   | 21                     | 48.8 (Main arch spacing) | 36.5 and 27.4 (Upper and lower bridge deck width) | 29.8 (Service width)  | 28 (Service width)  | 28 (Service width)  |
| Total length/m   | 923.6                  | 502.9                    | 932   | 756                   | 518   | 530                 |
| Steel usage for main structure/t                         | 15,503 (Arch)          | 37,000                   | 47,000  | 34,499 (Arch: 23,265) | 21,842  | 10,790 (Arch: 6720) |
| Steel usage index for whole bridge/ (t m <sup>-2</sup> ) | 1.425                  | 1.508                    | 0.789   | 1.531                 | 1.505   | 0.727               |
| Steel usage index for arch ring/ (t m <sup>-2</sup> )    | 0.799                  |                          |   | 1.032                 |   | 0.453               |
| Concrete usage/m <sup>3</sup>                            |                        |                          | 115,600   |                       | 29,400  | 26,933              |
| Horizontal hanger usage/t                                | 0                      | 0                        | 638   | 1760                  | 0   | 0                   |
| Welding thickness of steel plates/mm                     |                        |                          | 80  | 100                   |   | 34                  |
| In-tube concrete usage/m <sup>3</sup>                    | 0                      | 0                        | 0   | 0                     | 0   | 6400                |
| Arch ring lifting weight/t                               |                        |                          | 80  | 480                   |   | 200                 |

(continued)

**Table 1.1** (continued)

| Technical indicators  | Steel truss arch       |                      |                    | Steel box arch |   | CFST arch       |
|---|------------------------|----------------------|--------------------|----------------|---|-----------------|
|   | New River Gorge Bridge | Sydney Harbor Bridge | Chaotianmen Bridge | Lupu Bridge    | Bosideng Bridge (engineering feasibility study stage results) | Bosideng Bridge |
| Steel usage for construction measures/t                           |                        |                      | 40,000             | 11,000         |   | 4000            |
| Steel usage index for construction measures/ (t m <sup>-2</sup> ) |                        |                      | 0.67               | 0.48           |   | 0.28            |

importantly, when crossing a deep valley, a 600 m-span CFST arch bridge can replace a kilometer-scale suspension bridge, which has higher economic benefits.

- (3) The CFST arch bridges' low sensitivity to temperature variations makes them especially suitable for high-speed railway bridges.

In addition to being widely used on highways and urban areas, CFST arch bridges are also suitable to be built on high-speed railways due to their large stiffness and low sensitivity to temperature variations. Figure 1.4 shows the measured time-variant vertical displacement of the arch crown in one day of the Matan Hongshui River Bridge, which is a CFST arch bridge built on the Liuzhou-Nanning Expressway. It is a two-way eight-lane arch bridge with a main span of 326 m and the chord dimension of the main arch is 1200 mm in diameter and 22 or 32 mm in wall thickness. To investigate the effects of in-tube concrete on the vertical displacement of the chords,

**Fig. 1.1** Wuhan Han River Third Bridge



**Fig. 1.2** Wushan Yangtze River Bridge



**Fig. 1.3** Zhijing River Bridge on Shanghai-Chengdu Highway



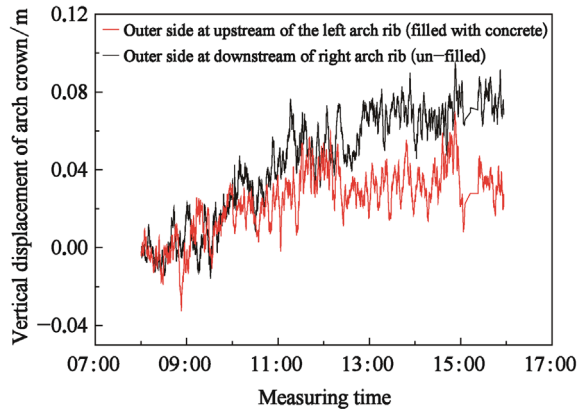
a one-day measurement was conducted at a specific construction phase when the chord tubes of one arch rib were filled with C50 concrete, while the chord tubes of the other arch rib were left empty.

The vertical displacement of the two arch ribs was recorded at the same time from 8:00 to 16:00 in one day. The measured results are depicted in Fig. 1.4 (the red curve denotes the arch ribs with in-tube concrete and the black curve denotes the chord without in-tube concrete). The results show that the black curve, i.e., the arch rib without in-tube concrete, rises and falls along with the changing daily temperature like a steel bridge, while the red curve, i.e., the arch rib with in-tube concrete, does not have an apparent vertical displacement.

(4) The CFST arch bridges possess good wind and earthquake resistance performance.

Owing to their high stiffness, CFST arch bridges with spans as large as 500 m generally do not need to be checked for wind resistance capability. With respect to seismic performance, one example is that the earthquake-resistant checking does not

**Fig. 1.4** The evolution of the vertical displacement of arch crown of Matan Hongshui River Bridge with time



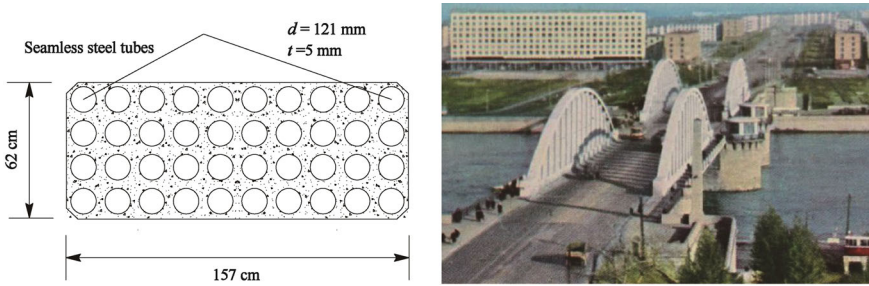
control the design of the 430 m-span Zangmu Yarlung Tsangpo River Bridge on the Lhasa-Nyingchi Railway, which is located in a seismic hazard zone of magnitude 9. The bridge was designed by China Railway Eryuan Engineering Group Co., Ltd., and constructed by China Railway Guangzhou Engineering Bureau Group Co., Ltd, and was opened to traffic in 2019. Moreover, there are several CFST arch bridges have undergone the test of the Wenchuan earthquake, and the post-earthquake detection shows that the earthquake caused only small damage to these bridges.

## 1.2 Development History of CFST Arch Bridges [3]

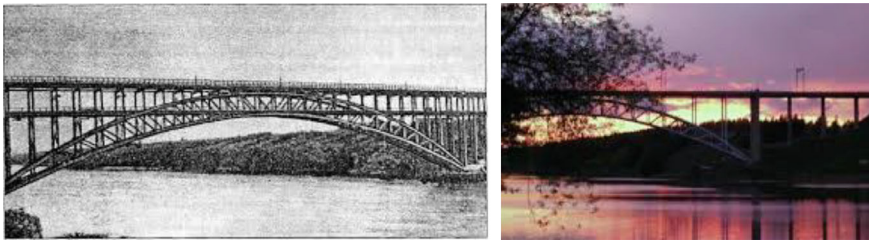
The first CFST arch bridge was constructed in 1937 in Leningrad, former Soviet Union (St. Petersburg, Russia). It was a 101 m-span through arch bridge using small-diameter clustered concrete-filled steel tubes to form the arch ring. Its cross-section and the completed bridge is shown in Fig. 1.5. Two years later, the former Soviet Union built another deck CFST arch bridge with a span of 140 m on the Ucerb River in Siberia, as shown in Fig. 1.6.

During the construction of these two bridges, steel tubes were segmented and filled with concrete, and then assembled together on external supports to form the arch ring. Such a construction method does not give full play to the structural advantage of the arch ring and the unnecessary of temporary supports due to the light weight of the steel tube arch truss. Therefore, in the following 50 years, no CFST arch bridges were built, which implied that the original CFST arch bridges were ruthlessly abandoned by the market.

In China, Chinese engineers have been dedicated to investigating the working mechanism and construction technology of CFST arch bridges for a long time [4], leading to the construction of China's first CFST arch bridge in 1990-the Wangcang East River Bridge. The bridge is a through CFST arch bridge with a main span of 115 m and a traffic deck width of 15 m. The main arch consists of two parallel



**Fig. 1.5** The 101-m-span CFST arch bridge across the Nerva River in Leningrad, the former Soviet Union



**Fig. 1.6** The CFST railway arch bridge with a span of 140 m on the Yisheji River, Siberia, the former Soviet Union

CFST arch ribs. Each arch rib possesses a dumbbell-shaped cross section, for which the diameter and wall thickness of the steel chord tubes are 800 mm and 10 mm, respectively. Each steel arch rib was divided into 5 segments, and was constructed using the cable-stayed fastening-hanging cantilevered assembly method, followed by arch closure while loosening the buckled cables, as shown in Fig. 1.7. Afterwards, an average of 18 CFST arch bridges have been built each year in China since 1993, totalling more than 500 CFST bridges have been built so far.

With the rapid development of the social economy and the continuous innovation of engineering technology, the increase in the number and the span length of CFST arch bridges in China is accompanied by the constant innovation of construction techniques and bridge structural forms. According to the incomplete statistics, by the end of 2017, there were about 462 CFST arch bridges having been constructed or under construction in China, of which 70 have a span of more than 200 m, 19 have a span of more than 300 m, 8 have a span of more than 400 m, and 3 have a span of more than 500 m (Table 1.2; Figs. 1.8 and 1.9). Within the bridges shown in Fig. 1.10, one bridge is especially noteworthy—the Bosideng Bridge (Fig. 1.10c). It is a CFST arch bridge across the Yangtze River on the Luzhou-Chongqing Expressway. With an effective span of 518 m, it is currently the world's longest CFST arch bridge in terms of main span. The bridge is 24.6 m in width and the total length of the bridge including the approach is 838 m. It started construction in 2010 and was

**Fig. 1.7** The Wangcang East River Bridge



completed in 2013. The steel tube arch truss segments of the bridge were lifted to position by suspension cables, and erected by the steel strand-assisted cable-stayed fastening-hanging cantilevered assembly method, followed by arch closure and loosening the buckled cables. The steel tube arch truss and traffic beam segments were manufactured in the shop, leading to a high shop prefabrication level of 85% and a totally formwork-free construction of the superstructure. The overall construction cost of the bridge is RMB 260 million yuan. It achieved excellent construction quality according to the completion acceptance test.

To ensure the successful construction of the Bosideng Bridge, long-term comprehensive research has been conducted and a series of significant achievements have been achieved as the following. Firstly, the relevant research projects titled “Innovative Technologies of CFST Arch Bridge with spans greater than 500 m” won the Second Prize of National Scientific and Technological Progress of China in 2018. Secondly, the project of the Bosideng Bridge won The China Civil Engineering Zhan Tianyou Award and The Lu Ban Award in 2018 and The International Bridge Conference (IBC) Award in 2019. Thirdly, the construction of the bridge also promoted the birth of the CFST arch bridge specifications in China, including the National Technical Code for Concrete-filled Steel Tube Arch Bridges (GB50923-2013) in 2013 [5], and Industrial Specifications for Design of Concrete-filled Steel Tubular Arch Bridges (JTG/T D65 06-2015) [6] issued by the Ministry of Transport of China in 2015.

In addition to the Bosideng Bridge, the Pingnan Third Bridge (Fig. 1.10a), which is a half-through CFST arch bridge with a main span of 575 m, is also under construction. It started construction in May 2018 and will be the world record holder in terms of the span of arch bridges when it is completed. Moreover, the 700-m scale CFST arch bridges are also under intensive feasibility study [7].

Overall, the impressive rapid increase in the number and span length of CFST arch bridges in China has created a miracle in the world’s bridge construction history. One underlying reason is that Chinese engineers have given full play to the inherent structural, construction, and cost advantages of the CFST arch bridges. In addition, it

**Table 1.2** A list of CFST arch bridges with spans greater than 200 m in China

| No | Bridge                               | Bridge type                      | Year of completion | Span/ m | Cross-section form | Rise- span ratio | Arch axis type       | Construction Method   |
|----|--------------------------------------|----------------------------------|--------------------|---------|--------------------|------------------|----------------------|-----------------------|
| 1  | Pingnan Third Bridge                 | Half through                     | Under construction | 575     | Four-tube truss    | 1/4              | Catenary m = 1.50    | Cantilevered assembly |
| 2  | Bosideng Bridge                      | Half through                     | 2013               | 530     | Four-tube truss    | 1/4.5            | Catenary m = 1.45    | Cantilevered assembly |
| 3  | Hejiang Yangtze River Highway Bridge | Flying swallow type              | Under construction | 507     | Four-tube truss    | 1/4              | Catenary m = 1.50    | Cantilevered assembly |
| 4  | Wushan Yangtze River Bridge          | Half through                     | 2005               | 460     | Four-tube truss    | 1/3.8            | Catenary m = 1.55    | Cantilevered assembly |
| 5  | Guizhou Daxiaojiang Bridge           | Deck arch                        | Under construction | 450     | Four-tube truss    | 1/4.5            | Catenary m = 1.55    | Cantilevered assembly |
| 6  | Zhijing River Bridge                 | Deck arch                        | 2009               | 430     | Four-tube truss    | 1/5.5            | Catenary m = 1.75    | Cantilevered assembly |
| 7  | Zangmu Yarlung Tsangpo River Bridge  | Half through                     | Under construction | 430     | Four-tube truss    | 1/3.84           | Catenary m = 2.10    | Cantilevered assembly |
| 8  | Liangshuigou Bridge                  | Deck arch                        | 2009               | 430     | Four-tube truss    | 1/5.5            | /                    | Cantilevered assembly |
| 9  | Xiangtan Liancheng Bridge            | Cable-stayed flying swallow type | 2007               | 388     | Six-tube truss     | 1/5.19           | Seven times parabola | Cantilevered assembly |
| 10 | Yiyang Maocaojite Bridge             | Flying swallow type              | 2005               | 368     | Four-tube truss    | 1/5              | Catenary m = 1.30    | Cantilevered assembly |
| 11 | Guizhou Zhuxi River Bridge           | Deck arch                        | 2014               | 360     | Four-tube truss    | 1/5.217          | Catenary m = 1.30    | Cantilevered assembly |

(continued)

Table 1.2 (continued)

| No | Bridge                                      | Bridge type         | Year of completion | Span/ m | Cross-section form    | Rise- span ratio | Arch axis type      | Construction Method   |
|----|---|---------------------|--------------------|---------|-----------------------|------------------|---------------------|-----------------------|
| 12 | Guangzhou Yajisha Bridge                    | Flying swallow type | 2000               | 360     | Six-tube truss        | 1/4.5            | Catenary m = 2.00   | Rotation construction |
| 13 | Jungar-Shuozhou Railway Yellow River Bridge | Deck arch           | 2011               | 357     | Four-tube truss       | 1/6              | Catenary m = 2.5    | Cantilevered assembly |
| 14 | Enshi Xiao River Bridge                     | Deck arch           | 2009               | 338     | Six-tube truss        | 1/5              | Catenary m = 1.543  | Cantilevered assembly |
| 15 | Matan Hongshui River Bridge                 | Half through        | Under construction | 336     | Four-tube truss       | 1/4              | Catenary m = 1.16   | Cantilevered assembly |
| 16 | Nanning Yonghe Bridge                       | Half through        | 2004               | 335     | Dumbbell-shaped truss | 1/4.5            | Four times parabola | Cantilevered assembly |
| 17 | Taiping Lake Bridge                         | Half through        | 2007               | 330     | Dumbbell-shaped truss | 1/4.94           | Catenary m = 1.55   | Cantilevered assembly |
| 18 | Chun'an Nantu Bridge                        | Half through        | 2003               | 308     | Four-tube truss       | 1/5.5            | Catenary m = 1.16   | Cantilevered assembly |
| 19 | Guizhou Xianghuoyan Bridge                  | Deck arch           | Under construction | 300     | Six-tube truss        | 1/5.5            | Catenary m = 1.54   | Cantilevered assembly |
| 20 | Fengjie Meixi River Bridge                  | Deck arch           | 2001               | 288     | Four-tube truss       | 1/5              | Catenary m = 1.50   | Cantilevered assembly |
| 21 | Dongguan Shuidao Bridge                     | Flying swallow type | 2005               | 280     | Dumbbell-shaped truss | 1/5              | Catenary m = 1.50   | Cantilevered assembly |
| 22 | Wuhan Hanjiang Third Bridge                 | Through             | 2000               | 280     | Four-tube truss       | 1/5              | Catenary m = 1.54   | Cantilevered assembly |

(continued)

Table 1.2 (continued)

| No | Bridge                                       | Bridge type  | Year of completion | Span/ m | Cross-section form    | Rise- span ratio | Arch axis type     | Construction Method   |
|----|--|--------------|--------------------|---------|-----------------------|------------------|--------------------|-----------------------|
| 23 | Yichang-Wanzhou Railway Yangtze River Bridge | Through      | 2007               | 275     | Dumbbell-shaped truss | 1/5              | Quadratic parabola | Rotation construction |
| 24 | San'an Yongjiang Bridge                      | Half through | 1998               | 270     | Dumbbell-shaped truss | 1/5              | Catenary m = 1.54  | Cantilevered assembly |
| 25 | Xiangshan Sanmenkou Northern Gate Bridge     | Half through | 2006               | 270     | Four-tube truss       | 1/5              | Catenary m = 1.54  | Cantilevered assembly |
| 26 | Xiangshan Sanmenkou Middle Gate Bridge       | Half through | 2006               | 270     | Four-tube truss       | 1/5              | Catenary m = 1.54  | Cantilevered assembly |
| 27 | Mengdong River Bridge                        | Deck arch    | 2017               | 268     | Four-tube truss       | 1/5.5            | Catenary m = 1.65  | Cantilevered assembly |
| 28 | Longqiao Bridge                              | Deck arch    | 2014               | 268     | Four-tube truss       | 1/5              | Catenary m = 1.50  | Cantilevered assembly |
| 29 | New Liujiang Yu River Bridge                 | Through      | 2018               | 268     | Four-tube truss       | 1/4.5            | Catenary m = 1.35  | Cantilevered assembly |
| 30 | Liulv Bridge                                 | Through      | Under construction | 265     | Four-tube truss       | 1/4.5            | Catenary m = 1.35  | Cantilevered assembly |
| 31 | Shimen Reservoir Bridge                      | Half through | 2017               | 262     | Four-tube truss       | 1/4              | Catenary m = 1.50  | Cantilevered assembly |
| 32 | Suichang Wuxi River Bridge                   | Deck arch    | 2017               | 260     | Four-tube truss       | 1/4.7            | Catenary m = 1.75  | /                     |
| 33 | Enshi Jinyang River Bridge                   | Deck arch    | 2008               | 260     | Four-tube truss       | 1/5              | Catenary m = 1.756 | Cantilevered assembly |

(continued)

Table 1.2 (continued)

| No | Bridge                         | Bridge type         | Year of completion | Span/ m | Cross-section form    | Rise- span ratio | Arch axis type        | Construction Method   |
|----|--------------------------------|---------------------|--------------------|---------|-----------------------|------------------|-----------------------|-----------------------|
| 34 | Rongzhou Jinsha River Bridge   | Half through        | 2004               | 260     | Four-tube truss       | 1/4.5            | Catenary m = 1.40     | Cantilevered assembly |
| 35 | Zhoushan Songao Bridge         | Half through        | 2007               | 260     | Four-tube truss       | 1/5.443          | Catenary m = 1.15     | Cantilevered assembly |
| 36 | Beishengou Bridge              | Half through        | 2010               | 260     | Dumbbell-shaped truss | 1/4.5            | Catenary              | Cantilevered assembly |
| 37 | Zigui Qinggan River Bridge     | Half through        | 2002               | 256     | Four-tube truss       | 1/4.945          | Cubic spline function | Cantilevered assembly |
| 38 | Guang'an Kuige Qu River Bridge | Flying swallow type | 2011               | 256     | Four-tube truss       | 1/4.5            | /                     | Cantilevered assembly |
| 39 | Qiandao Lake No.1 Bridge       | Deck arch           | 2006               | 252     | Dumbbell-shaped truss | 1/6.5            | Catenary m = 1.756    | Cantilevered assembly |
| 40 | Qin River Bridge               | Half through        | 2012               | 252     | Three-tube truss      | 1/4.324          | Catenary m = 2.20     | Cantilevered assembly |
| 41 | Hailuo Mengdong River Bridge   | Deck arch           | 2012               | 251     | Four-tube truss       | 1/5.5            | Catenary m = 1.65     | Cantilevered assembly |
| 42 | Wuhan Changfeng Bridge         | Flying swallow type | 2000               | 251     | Dumbbell-shaped truss | 1/5              | Catenary m = 1.50     | Cantilevered assembly |
| 43 | Sanmen Jiantiao Bridge         | Half through        | 2001               | 245     | Dumbbell-shaped truss | 1/5              | Quadratic parabola    | Cantilevered assembly |
| 44 | Guizhou Luojiao River Bridge   | Half through        | 1998               | 240     | Five-tube cluster     | 1/4              | /                     | /                     |
| 45 | New Wushan Longmen Bridge      | Half through        | 2010               | 240     | Dumbbell-shaped truss | 1/5              | Catenary m = 1.50     | Cantilevered assembly |

(continued)

Table 1.2 (continued)

| No | Bridge  | Bridge type         | Year of completion | Span/ m | Cross-section form    | Rise- span ratio | Arch axis type     | Construction Method             |
|----|---|---------------------|--------------------|---------|-----------------------|------------------|--------------------|---------------------------------|
| 46 | Wuhan Jiangnan Fifth Bridge                       | Flying swallow type | 2000               | 240     | Dumbbell-shaped truss | 1/5              | Catenary m = 1.50  | Cantilevered assembly           |
| 47 | Xiangshan Tongwamen Bridge                        | Half through        | 2001               | 238     | Double- tube truss    | 1/4.324          | Quadratic parabola | Cantilevered assembly           |
| 48 | Liupanshui-Baiguozhen Railway Beipan River Bridge | Deck arch           | 2001               | 236     | Dumbbell-shaped truss | 1/4              | Catenary m = 3.20  | Rotation construction           |
| 49 | Xuzhou Jinghang Grand Canal Bridge                | Flying swallow type | 2002               | 235     | Four-tube truss       | 1/4              | Catenary m = 1.33  | Rotation construction           |
| 50 | Guizhou Wangtuo Wu River Bridge                   | Half through        | 2011               | 230     | Four-tube truss       | 1/5              | Catenary m = 1.54  | Cantilevered assembly           |
| 51 | Nanchang Shengmi Bridge                           | Flying swallow type | 2005               | 228     | Dumbbell-shaped truss | 1/4.5            | Quadratic parabola | Cantilevered assembly           |
| 52 | Ling-Nan Highway Pushan Bridge                    | Through             | 2009               | 225     | Four-tube truss       | 1/5              | Quadratic parabola | Bracket -supported construction |
| 53 | Enshi Nanniadu Bridge                             | Deck arch           | 2002               | 220     | Four-tube truss       | 1/5              | Catenary m = 1.75  | Cantilevered assembly           |
| 54 | Liuqing Yu River Bridge                           | Half through        | 1999               | 220     | Four-tube truss       | 1/5              | Catenary m = 1.54  | Cantilevered assembly           |
| 55 | Laibin Laithua Bridge                             | Half through        | 2012               | 220     | Four-tube truss       | 1/3.5            | Catenary m = 1.54  | Cantilevered assembly           |
| 56 | Ziyang Ximenhe Han River Bridge                   | Half through        | 2014               | 220     | Dumbbell-shaped truss | 1/4.5            | Quadratic parabola | Cantilevered assembly           |

(continued)