ARCH BRIDGES IN CAMPUS CULTURE OF FUZHOU UNIVERSITY

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SUMMARY

Fuzhou University is one of the national key universities in China and the most important comprehensive university in Fujian Province. Civil engineering, especially bridge engineering, is one of the most important engineering courses in the university, and the research and application of arch bridges enjoys a good reputation in the country. In the main running campus--Qishan campus, there are many arch bridges with short spans, which are carefully designed to be a landscape of the campus and to be a representative of the latest technology of arch bridges developed by the university. This paper introduces the arch bridges in Fuzhou University and the culture in the campus, focusing on four kinds of arch bridges, i.e., a stone arch bridge and a timber arch bridge (woven timber arch bridge) inheriting the traditional arch bridge in China and especially in Fujian Province, a concrete-filled steel tube (CFST) arch supported stress ribbon bridge with a special architecture design, and a ultra-high performance concrete (UHPC) arch bridge using the advanced high technology material.

Keywords: *Arch bridges, culture, campus, architecture, technology, heritage, Fuzhou University.*

1. INTRODUCTION

Fuzhou University (FZU) is one of the national key universities in China and the most important comprehensive university in Fujian Province, giving priority to engineering courses while including other fields like sciences, economics, management, liberal arts, law, arts and design, etc. In the university, bridge engineering is one of the most important engineering courses and the research and application of arch bridges enjoys a good reputation in the country.

The university covers more than 333 hectares. The main running campus is located in Qishan campus of the University Town of Fuzhou Region. Qishan campus is located in the north of Min River and in the south of the Qishan (mountain). There is a hill name Chang-an-shan with a height of 62m in the south of the flat terrain of the campus, surrounded by multiple lakes connected by water system. It is planned to have boats on the water for relaxation life in the campus and tourist for guests. In order to meet the requirement of space under the bridge for boats, and also for the aesthetics of a bridge, arch bridges are favoured to be built and they have become the landscapes of FZU Campus. At the same time, they inherit the traditional culture of arch bridge in China,

reflect the technology development trend of the arch bridge, and form the unique campus culture of FZU. Four kinds of typical arch bridges are introduced in this paper, and their locations can be found in Fig. 1.

Fig. 1. *Map of the five Arch bridges in FZU Campus.*

2. TIMBER ARCH BRIDGES

China timber arch bridge is an unique structure, made by straight logs woven together in a special way without nails and ropes, so it is also called woven arch bridge. The main arch consists of two longitudinal polygonal arch systems connected by transverse systems, and its construction is convenient because members are light and need less processing. From the historical records, China timber arch bridge can be traced back to 1032 to 1033 when the first one was built, the structures can be seen from a bridge in the famous painting of "Chhing-Ming Shang Ho Thu" (Festival of Pure Brightness on the River) by Zhang Zeduan, shown in Fig. 2a) [1]. Investigation indicated that there are 128 timber arch bridges in service in Fujian and Zhejiang Province of China [2]. Among them, there are only six multi-span bridges, in which one bridge with six spans, two bridges with three spans and three bridges with two spans [2]. A typical up-view of the bridge is shown in Fig. 2b.

Nowadays, research and protection of China timber arch bridge are hot topics in the fields of ancient bridges and cultural heritage in China. Many researches have been carried out by cultural relics workers and architects, focusing on the construction history, aesthetics, social function, cultural value and so on. In FZU, the research focuses on major structure behavior and principle, the construction technology from the view of bridge engineering under the support from China National Science Funding (No. 51408129).

As a part of the research results, two timber arch bridges have been built in FZU Campus, one is located on the way from the University Administration Building to the Library and the other is located on the way from the same building to the landscape avenue, as shown in Fig. 1.

a) Painting (part)

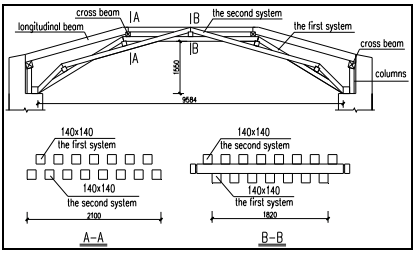
b) Up-view of a bridge

Fig. 2. *China timber arch bridge.*

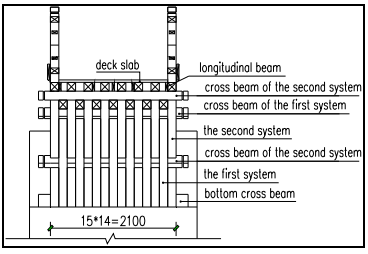
a) Bridge I in front view

b) Bridge II in side view

c) Bridge I in a bird view



d) Main arch structure



e) Cross section of the crown arch

Fig. 3. *Timber Arch Bridges in FZU Campus.*

Figure 3a-c show the photos of the two bridges. Both of them have the same structure, composed of two systems. The first system is made up of three-line polygonal arch ribs, with 7 rows in the transverse direction; whereas, the second system is made up of four-line polygonal arch ribs, with 8 rows in the transverse direction [3].

China timber arch bridges are designed and built by bridge craft workers. The technology has been handed down from masters to their apprentices, but faces a lost danger today. It was listed in the Urgent Safeguarding List of Intangible Cultural Heritage by UNESCO in 2009 [3]. These two bridges are constructed by a construction company following the traditional techniques but not craft workers.

Woven arch bridge is neither a traditional plan structure nor a spatial structure. These two bridges in the campus give real examples for students to understand the structure details and the principle. Therefore, these two timber arch bridges not only are a structure to cross over water as a bridge and improve the landscape of the campus as an architecture, but also link the ancient technology to modern one, verifying that it is possible to record the ancient construction technology by today's bridge engineering knowledge, and link the research work to education, serving as real models for students to observation. Furthermore, the research and protection of the ancient structure can not only inherit our valuable legacy, but also serve for our today's life.

3. STONE ARCH BRIDGES

Stone arch has long history in China. Many historic arch bridges experienced thousands of years and are still in service today. Some of them are very famous in the world, such as the Chaw-Zhou Bridge, the Lugou Bridge (Marc Polo Bridge). Rich structure types and details can be found in the ancient stone arch bridges, varying from place to place and from time to time. In Fujian Province, the ancient stone arch bridges have their special prestige. For example, the Gao-pei Bridge located in Yongding, built in 1477 and rebuilt in 1775, has a span of 20 m and a depth of only 60 cm. It is a typical thin ring stone arch bridge in China.

In China, stone arch bridges are not only built in the ancient time, but also widely adopted in highways in 1950-1970s. After that, they are still used in hilly or mountainous areas, such as the two stone arch bridges designed by the first author of this paper in 1990s [4].

Stone arch bridge is not an economy solution today, and hence few are built after 1990s. But many of them built before are still in service in the road system. From an investigation, there are 1936 stone arch bridges in service in the local highways of Fujian Province, accounted for 52% of the total 3729 bridges by the end of 2002 [4]. Research on repair, rehabilitation and strengthening of stone arch bridges is also an important research topic in FZU. Stone arch bridge is still an important content in course of "Bridge Engineering" for undergraduate students in China.

In the FZU, there is a stone arch bridge with three spans, as shown in Fig. 4. The bridge is located on the way from Students' Quality Development Centers to the University Administration Building, as shown in Figure 1. It is an open-spandrel arch bridge. The width of bridge is 10.56 m. The main arch has a clear span of 12 m and a rise of 2.5 m. Two sides span is 8 m in length with a rise of 1.6 m. This bridge is the only arch bridge for traffic in the campus while another four bridges are for passengers.

Fig. 4. *Stone Arch Bridges in Fuzhou University Campus.*

4. PEDESTRIAN UHPC ARCH BRIDGE

The pedestrian UHPC arch bridge is located in the bank of two lakes in front of the south administration building, as shown in Figure 1. It is a small bridge with a span of only 10m. The material in the main arch is ultra-high performance concrete (UHPC) with a compressive strength of 130MPa. Therefore, the arch ring is as thin as 10cm, giving a very shallow structure with a ratio of depth-to-span of only 1/100.

The concept of UHPC was first proposed in 1994 [5, 6]. Researches and applications of UHPC have been carrying out since late 1990s in China, especially in bridge engineering. As one of the main universities in this field, FZU has started the research since 2000 and now are focusing on its application in arch bridges. A key project "Holistic Research on Designs of Ultra-high Performance Concrete and Its Engineering Application" funded by National Natural Science Foundation of China in 2013 under Grant No. U1305245 is coordinated by FZU at present. Material mix technology of UHPC with local materials, experimental research on UHPC material properties, structures such as girders, columns and arches, calculation methods and finite element analysis method for UHPC structures, trial designs of UHPC girder bridges and arch bridges with a span of 160m, 420m and 600m have been conducted. The first UHPC highway bridge in China was designed by FZU and built in 2015 [7].

It is well known that concrete is an ideal construction material for arch bridges, since the structure is mainly subjected to compression forces while concrete has high strength in compression. However, the construction difficulties and costs increase with the span length, due to the increase of concrete arch self-weight. Therefore, it is probably safe to say till today that higher is better for material performance for long span concrete arch bridges and UHPC is predicted to be used more and more in arch bridge in future [8]. However, as a new material, it is difficult to find a chance to apply in real engineering especially for a long span bridge. Hence, the small pedestrian bridge in FZU is a good chance for UHPC application, which may provide experiences for the engineers and encourage more UHPC bridges to be built in China.

The arch has a rise of 2.5 m, giving a rise-span ratio of 1/4. The arch axis is a segmental circle with a radius of 6.25 m. The width of the bridge is 2.1 m. The spandrel walls, abutment as well as the foundation were made by normal concrete structures. The elevation of the bridge is shown in Fig. 5a.

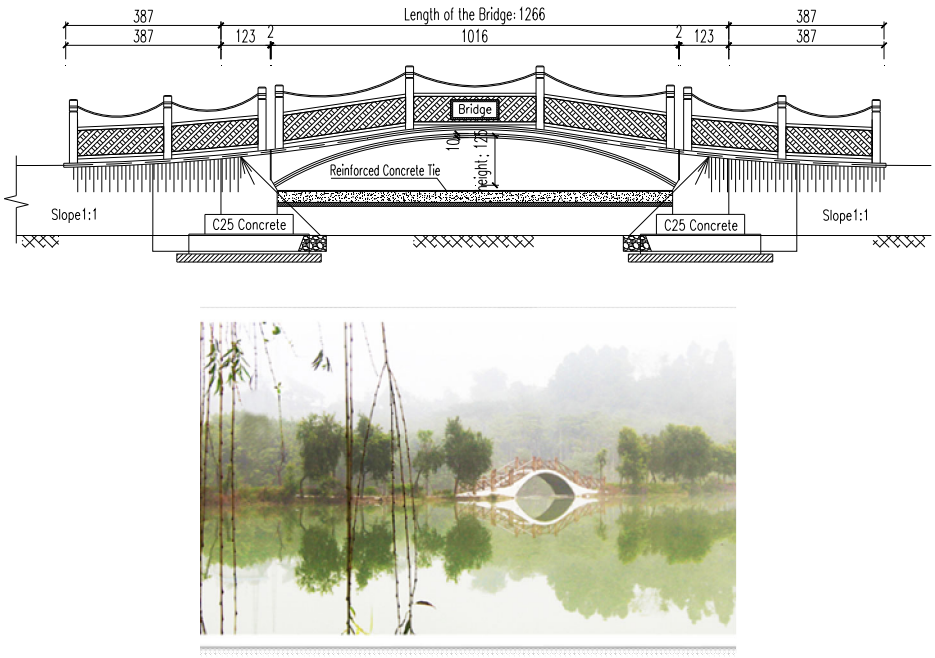


Fig. 5. *UHPFRC arch bridge in FZU Campus: a) Elevation (unit: cm) b) Photo.*

The arch structure with the graceful curve of the main structure and the timber guardrails as its two architecture features was selected as the solution, because it can be harmony with the surroundings of green trees in the banks, the lakes as well as rest booth nearby. The typology of the bridge simulates the ancient China stone arch bridge with segment arch but much thinner to show a modern architecture style and advanced technology of material and structure. The completed bridge is displayed in Fig. 5b.

5. CFST ARCH SUPPORTED RIBBON BRIDGE

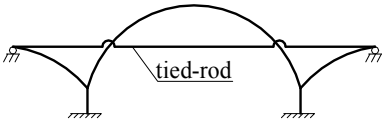
The CFST arch supported ribbon bridge, the Wolong Bridge, is located in the landscape avenue of the FZU campus, as shown in Figure 1. The landscape avenue is in the central axis of the campus connecting the main gate and the library, which is the center of the campus, with green land at the north side and wetland in the south side. The avenue is 36 meter wide, filled with flower beds and a greenbelt in the middle, constructed to celebrate the 55th anniversary of FZU in 2013. Each of the two sidewalks in the avenue has a width of 6.7 m.

Two separated bridges with the same structure form were designed according to the traffic function design of the landscape avenue. The topography of the bridge site is subdued along the avenue. The subgrade is composed of fine-grained soil in the middle humidity. More than 3 m height clearance under the bridge is required for planed boat navigation. The bridge construction site is located in low-lying flat ground, and the difference of elevation between the road and the water is only 1.5 m. Therefore, an arch

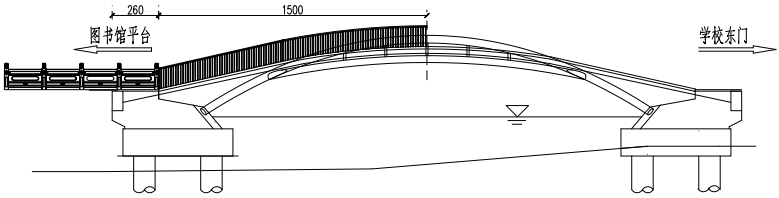
structure is a reasonable solution for this bridge. Considering the natural condition of the construction site, the bridge span is designed to be 25 m, some shorter than the natural water surface. A half-through bridge with a main span of 25 m is adopted. The main structure is concrete-filled steel tube (CFST) arch ribs tied by cables to balance the arch horizontal thrust.

In the last two decades in China, balancing arch thrust by employing cables is a general solution for CFST arch located in soft foundation, such as the half-through rigid-frame tied arch bridges, also named fly-bird-type arch bridges, as shown in Fig. 6a [9, 10]. For the pedestrian bridge in the FZU campus shown in Fig. 6b, the tie rod is utilized for the support structure for bridge decks as in the ribbon stress bridge. The side spans are degenerated into part of the abutment to have only one span but not three spans as illustrated in Fig. 6a. Through this change, the structure of the Wolong Bridge shares a similar characteristics of stress ribbon & arch bridge, which was proposed by Strasky [11], as shown in Fig. 6c. In a stress ribbon & arch bridge, the tension forces from the stress ribbon will balance with the thrust forces from the arch at the abutment, and hence the structure forms a self-anchoring system.

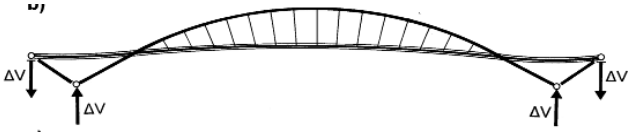
As the key structure in the landscape avenue of the campus, the bridge should have a good landscape effect to reflect the lively characteristics of the youth in the university. Outside inclined arch ribs are introduced in this bridge to simulate wings of butterflies, implying nice love from a legendary Chinese love story and thriving of the students. This landscape pedestrian bridge uses steel pipes as main material, which were painted in blue to match ideally with the library, the key architecture of the campus, meanwhile to be harmonic with the surroundings and cultural atmosphere, as shown in Fig. 7 [12].



a) Fly-bird-type Arch



b) Elevation of the Wolong Bridge in FZU



c) Half-through stress ribbon & arch

Fig. 6. *Structure of arch supported ribbon Bridge.*

a) View from the road

b) side view

c) Full view

Fig. 7. *The Wolong Bridge--CFST arch supported ribbon bridge in FZU campus.*

6. OTHERS

In the last two decades, CFST arch bridge is a main topic in bridge engineering of FZU. A series of results were obtained, including design for consultants directly on many CFST arch bridges, experimental and theoretical research for establishment of the design calculation theory, editing specifications as well as papers and books for publication [13]. This feature and achievements are reflected in the CFST arch ribs of the Wolong Bridge (Fig. 7) and also the structure of a carport as shown in Fig. 8 in the front square of the College of Civil Engineering.

Fig. 8. *CFST Carport in FZU campus.*

Many arch models after tests are remained in the model garden around the labs of College of Civil Engineering, as shown in Fig. 9. These models can not only provide a real model for academic exchange and education, but also as a special landscape of the FZU campus.

a) CFST truss arches *b) CFST arch with corrugated webs* *c) CFST single tube*

d) RC arch with corrugated webs *e) RC arch with tube webs arches* *f) UHPC arches*

Fig. 9. *Arch models in FZU campus.*

7. LAST REMARKS

Arch bridge is one of the main types of bridges, and plays a very important role in transportation for human society from ancient times to today. There is no doubt that arch bridges are beautiful, functional, understandable and in expressive form. Arch bridges have enriched their surrounding landscapes, while some become emblems and even a very important culture of the cities and villages. The arch bridges in the FZU campus were designed and constructed as landscapes to reflect the arch bridge heritage in the country and the province, to represent latest technology of arch bridges developed by the university, and to represent a special campus culture of the university.

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REFERENCES

[1] YANG Y., CHEN B.C., GAO J. Timber arch bridges in China, *Proceedings of the Fifth International Conference on Arch Bridge,* pp. 171-178, Madeira, Portugal. 2007.

[2] YANG Y., NAKAMURA S., CHEN B.C, NISHIKAWA T., A survey on existing China timber arch bridges, *Proceedings of Structures and Materials, Japan Society of Civil Engineering (JSCE),* pp. 61-68, 2012.

[3] YANG Y., NAKAMURA S., CHEN B. C., NISHIKAWA T., Traditional construction technology of China timber arch bridges, *Journal of Structural Engineering*, Vol.58, A.3, pp. 777-784, 2012.

[4] OU Z. J., CHEN B. C., Present situation and maintenance of Masonry arch bridges in Fujian Province of China, *Proceedings of the Fifth International Conference on Arch Bridge*, pp. 267-274, Madeira, Portugal, 2007.

[5] LARRARD D. F., SEDRAN T., Optimization of ultra-high-performance concrete by the use of a packing model. *Cement and Concrete Research*, pp. 997-1009. 1994.

[6] RICHARD P., CHEYREZY M., Reactive powder concretes with high ductility and 200–800 MPa compressive strength, ACI SP., 144(24), pp. 507-518, 1994.

[7] CHEN B. C., HUANG Q. W., SHEN X. J., GUO B, Two pilot UHPFRC bridges in China. *Proceedings of the 1st International Symposium of ACF on Ultra High Performance Concrete*, pp. 83-92. Klokata, India, 2015.

[8] CHEN B. C., HUANG Q. W., ŠAVOR Z., Material performance for long span concrete arch bridges: higher is better, *Proceedings of 8th International Conference on Arch Bridges*, Wroclaw, Poland, 2016.

[9] CHEN B. C., GAO J., ZHENG H. Y., Studies on behaviours of CFST "fly-bird-type" arch bridge, *Proceedings of the International Conference on Bridges*, 205-212. Dubrovnik, Croatia, 2006.

[10] LIU J. P., CHEN B. C, ZHOU J., WEI J. G., Application of concrete-filled steel tube arch bridges in China. *Proceedings of 8th International Conference on Arch Bridges*, Wroclaw, Poland, 2016.

[11] STRASKY J., Stress ribbon & arch pedestrian bridges. *Proceeding of 6th International Conference on Arch Bridge*, Fuzhou, China, 2010.

[12] CHEN B. C., HANG L. AND WANG Y. Y., Design of landscape pedestrian bridge in the campus central axis of Fu-zhou University, *China and Abroad Highway*, 34(5), pp. 115-118, 2014.

[13] CHEN B. C., WEI J. G. AND WU Q. X., China technical code for CFST arch bridges. *Proceedings of 8th International Conference on Arch Bridges*, Wroclaw, Poland, 2016.