

Timber arch bridges in China

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ABSTRACTS :The timber arch bridge, which is not only bridge engineering and architecture, but also cultural and historical heritage, has permanent aesthetic fascination and great research value. Ancient Biahe Rainbow Bridge and its structure are introduced with a famous painting at first. Then the extant Fujian-Zhejiang timber arch bridges are highlight with some typical bridges with photos. In these two timber arch bridge types in China, the main arch rings are woven from longitudinal and transverse straight logs. Differences between these two types discussed and other remarks on some problem remained and need for future research works are pointed out.

1 ANCIENT BIAHE RAINBOW BRIDGE

In china, rainbow bridge can be used to call all types of arch bridges to express the good emotion for its convenient transportation and its good looking appearance. However, in this paper it only means the timber arch bridge constructed by weaving straight logs crisscross together.

According to historical records, the first timber arch bridge was built by Xia Shouqing, military commander of Qinzhou, Shandong Province, in years of 1032-1033, who adopted the idea of a jailer, to consolidate the river banks with large stones, and then tying dozens of large timbers together so that they spanned the river without piers. Later, a rainbow bridge was also built in Suzhou, Anhui Province, by Chen Xiliang (a military commander of the city). After that time, rainbow bridges were set up in several places over the Fen and Bian rivers, greatly benefiting the local people, who called them rainbow bridges (Ministry of Communication of the People's Republic of China, 2003).

However, no rainbow bridge built that time survived. Thanks to artist Zhang Zeduan, a rainbow bridge can be seen in his famous painting of "Chhing-Ming Shang Ho Thu" (Festival of Pure Brightness on the River), as shown in Fig.1. The painting described scenes of daily life at Bianliang City, Dongjing (now Kaifeng, Henan Province), capital of Northern Song Dynasty (1119 to 1125). The rainbow bridge crossed over Bianhe (Bia River), so it is called Biahe Rainbow Bridge.

From the painting, a sketch of the bridge structure was drawn as in Fig. 2 and some structural data was estimated as follows (Mao Yisheng 1986, Ministry of Communication of the People's Republic of China, 2003):

It was 19.2m long and 8-9m wide, and there were 21 groups of log arch frameworks arranged in parallel. The diameter of the logs was about 40cm, and the framework was divided into two systems, of which the outer group was the first system, composed of two long arch frameworks and two short ones, while the inner group was the second system, consisting of three arch frameworks of the same length. Eleven groups of the first system and 10 groups of the second system formulated the intersection point at the timber frame of the two systems. Five logs were laid to traverse the whole bridge, playing the role of connecting arch frameworks, stabilizing the structure and distributing the live load in the transverse direction. The bridge abutments on both

banks were made of hard rocks to bear the thrust of the arch, and road was designed in front of the abutment. So the structure of this kind of bridge was rational and the design was ideal.

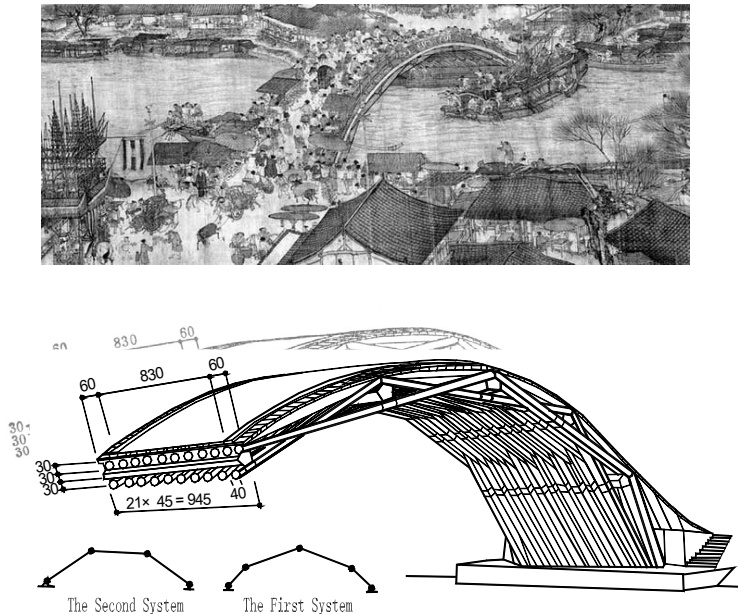


Fig.2: Sketch of the Rainbow Bridge Structure

From the previous analyses, it can be seen that ancient timber arch bridge—rainbow bridge in China consisted of longitudinal and transverse systems, which constituted a square on a plane. There were two groups of timber members in longitudinal systems; one group had one more member in a plan than the other group. The two groups were tied and interwoven by the transverse timber members to form rafts. The longitudinal members pressed on the transverse ones and likewise the transverse one pressed on the next longitudinal ones. In this way, two beams holding one beam, and the friction makes them impossible to move or damage the structure. The structure in general is an arch structure, the longitudinal members were dominated to press forces. However, not exactly as stone arch, the transverse beam acted on the middle of the longitudinal one will create bending moment in it. At the same time, timber has a great tensile strength than stone material so it is reasonable to carry some bending moments in timber arch.

It is well-known that stone arch bridge has long history in China and achieved high prestige in China, such as the Chaw-Zhou Bridge, completed in 605, with a span of 37.4m. However, the rainbow bridge had a large crossing capacity than stone arch bridge. Historical records indicate that the longest span of a timber arch bridge was 40m, exceeding the span of the Chaw-Zhou Bridge. Moreover, timber members in rainbow bridge is much lighter than stone ones, easy to be transported, no artificial components needed for special requirements and it can be built in weak foundation. Therefore, this bridge type was widespread in the center region of China in eleventh and twelfth century.

However, along with the breaking of wars, reduction of the timber resources, and the development of the other bridge type, timber arch bridge has vanished in this area nowadays. In the central and north area of China where at ancient time there were many rainbow bridges, we can only found rainbow bridge technology heritage in the Baling Bridge in Gansu Province, which was completed in 1398 and rebuilt in 1919 and 1923. It has 40.2m in total length with the span of the largest arch measuring 27.4m, as show in Fig.3. The bridge is a combination structure, in which it is timber cantilever at the spring and timber arch at crown (Ministry of Communication of the People's Republic of China, 2003).



Fig.3: The Baling Bridge in Gansu Province

2 EXTANT FUJIAN-ZHEJIANG TIMBER ARCH BRIDGES

It was considered that the rainbow bridge techniques had lost for a long time until 1970's when many timber arch bridges were found. The statistics from all the available sources show that about one hundred timber arch bridges survived in south-east of China, most of them are located in mountainous areas in southeast of Zhejiang Province and northeast of Fujian Province, as shown in Table 1(Mao 1986).

Table 1: Timber arch bridges in China

No.	Location		Amount	No.	Location		Amount
	county	province			county	province	
1	Shouning	Fujian	19	8	Xiapu	Fujian	1
2	Pingnan		13	9	Ningde		1
3	Zhouning		8	10	Wuyisan		1
4	Gutian		6	11	Taishun		7
5	Fu'an		4	12	Qingyuan	Zhejiang	22
6	Zherong		2	13	Jingning		19
7	Fuding		1				

These extant bridges are similar to the ancient rainbow bridge, but they are practically different in construction. Thus they are called as the extant Fujian-Zhejiang timber arch bridges here. Before discussion of the differences and historic relations between these two bridge types, some typical extant Fujian-Zhejiang timber arch bridges are introduced.

The oldest and the longest bridges among the extant timber arch bridges is the Wan'an Bridge. It is also called as Gongji Bridge, crossing the Changqiao River in Pingnan County, Fujian Province, as shown in Fig. 4. This bridge was built in 1090, refaced in 1708 and rebuilt in 1845, 1932 and 1953 respectively. The bridge has six spans with a total length of 97.4m and 4.7m wide. The longest span is 15.3m and the shortest one is 10.6m. The piers were made by granite. The bridge has 37 lounge houses and 152 pillars with a single-eaved roof, serviced as a shrine.

Fig.5 shows the Luanfeng Bridge, with longest single span of 39.7m. It cross Chang brook in Shouning County, Fujian Province. It was rebuilt in 1800 and 1963 respectively, but it is not clear when the it is first built. It is 47.6m in total length and 4.9m wide. One spring of the arch was built on the rock directly; the other one was on the pier of stone. The main arch ring was constructed with round log, and the deck slab utilized boards. The bridge is still in good condition as footway. There are 17 lounge houses over the bridge with 72 pillars and a single-eaved roof. All of the side of the arch and the house are covered by boards to prevent timber member to raining and the house is also local shrine.



(a) Side view

(b) Up view of the arch

Fig .4: Wan'an bridge

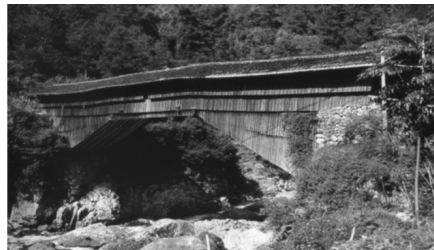


Fig .5: Luanfeng Bridge

Wuyishan in Fujian Province was listed in The Natural and Cultural Heritage of the World by the United Nations in 1999. Yuqing Bridge is located in this famous scenery. It was built in Yuan Dynasty (accurate time is not clear), rebuilt in 1887, and repaired in 1982. The bridge crosses the Chongyan River with three spans, has a total length of 77m and each span of 23.7m, see Fig. 6(a). The bridge is wide of 5.4m. The piers were constructed of stone with a beautiful diversion stone carving in bird head shape, as shown in Fig. 6 (b). A brick entrance gate in local architectural style (Fig. 6 (c)) stands at each end of the bridge, covered with roof, providing a public place for release for passengers, entertainment as well as other sanitary activities (Lin and Ke 2004).



(a) General view

(b) Diversion stone in the pier

(c) Entrance gate

Fig .6: Yuqing Bridge

Xianju Bridge (Fig. 7) is located at Taishun, Zhejiang Province. It was built in 1452 in Ming Dynasty has a length of 41.83m with a width of 4.89m and a span of 34.14m. The bridge has 19 lounge houses and 80 pillars with a single-eaved roof.



(a) Side view



(b) Inside view of house on the bridge

Fig.7 :Xianju Bridge

Xidong Bridge (Fig. 8) and Beijian Bridge (Fig. 9) are other two timber arch bridges located in Taishun, crossing the same river—Dongxi in Xiaqiao Village, share the same basic form, built by the master and the apprentice respectively. Therefore they are locally called as “Sister Bridges”. Informally, Xidong Bridge is also called as Upper Bridge and Beijian Bridge as the Lower Bridge. Xidong Bridge was built in 1570 and refurbished in 1754. It is bearing 15 lounge houses and 76 pillars, 41.7m long, 4.86m wide with a span of 25.7m. Beijian Bridge was built in 1674 and refreshed in 1849. It has 51.7m long, 5.37m wide with a span of 29m. Both of them have lounge houses with double-eaved roofs.



Fig.8 : Xidong Bridge

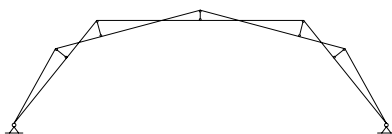


Fig.9: Beijian Bridge

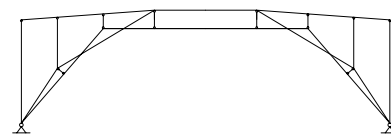
3 COMPARISONS BETWEEN TWO TIMBER ARCH BRIDGE TYPES

Both the ancient Rainbow Bridges and the extant Fujian-Zhejiang timber arch bridges are timber bridges, woven by longitudinal and transverse logs to form an arch structure. However, there are some differences between them.

Fig. 10 shows the main structures of the two bridge types. In the ancient Rainbow Bridge, it is odd number of the member in the first longitudinal system and even number in the second one. But two of them are even numbers in extant Fujian-Zhejiang timber arch bridge. Mechanic analyses by FEM show that the timber members in the latter bridge bearing larger bending moments than those in the former one.



(a) Ancient rainbow bridge



(b) Extant Fujian-Zhejiang timber arch bridge

Fig.10: Structures of timber arch bridges in China

The pillar connection in longitudinal system in extant timber arch bridge is made for a joggle joint (Fig. 11 (a)), not enlaced by strips as in Rainbow Bridge. In addition, it is found in the extant timber arch bridge that X-bracings are used to stabilize the longitudinal systems (Fig. 11 (b)).



Fig.11: Upward view of Xianju Bridge

The ancient rainbow bridge shaped in arc with the extrados stepped for pedestrians. However, in the extant Fujian-Zhejiang timber arch bridges, the arch shape is not as steep as the ancient one; it looks like a polygon and for a long time was considered as strut-framed bridge under the side-covering boards. Moreover, it has a deck system also made by timber boards.

The other differentiates is that the extant timber arch bridge adopt the form of a lounge bridge by building houses on it. In the border mountainous area of north Fujian and south Zhejiang (China southeast mountainous area), various timber bridges have been built with house to prevent the eroding from its abundant raining, this bridge type is called as lounge bridges. For a timber arch bridge, the arch ring has a good performance for pressure and it can carry larger downward load than its relatively light dead loads when both ends are well fixed. However, if the arch is subjected to an upward force, it is easy lose the balance. Therefore, the house on it can add more weight to the bridge body so as to prevent the attacks from the winds and torrents. Sometimes, when a timber arch bridge was subjected to destruction at any moment by the erupted mountain torrents and increased water level, the local villagers would take out their heavy furniture onto the surface of the bridge and successfully secured the stability of the bridge over the disastrous period of mountain torrents (Liu and Shen 2005).

Various houses on the bridge make the extant timber arch bridge rich and colorful in their appearances with obviously local architecture culture. The houses also serve as a resting place for travelers through the mountainous path. It also provides a place for villagers talking, trading and religion activities.

On large scale timber arch bridge, there is always a shrine of idols for villagers to offer sacrifice to. The shrine or even a temple may be arranged in the lounge houses or next to the bridge or facing the entrance of the bridge. In the lounge house, the idol always is rested by the side of downstream direction, facing the river flow. This arrangement has a special meaning, for one of the values of the idol is to resist the water flow and bring peace to the lounge bridge, and also for the local people peace lives and prospects.

4 NEW TIMBER ARCH BRIDGES

At present, some imitated timber arch bridges have been built in parks or gardens in China. Some of them are real timber arch bridges, some of them are false one. Pu Qing Bridge in the town of Jinze, Shanghai (Carla Ceraldi and Ennio Russo Ermolli 2004) and the bridge in Hangzhou shown in Fig. 12 are real timber arch bridges. They are imitation from the ancient rainbow bridge but not the extant Fujian-Zhejiang timber arch bridge though they are located in the south-east of China. But it is surprised for us to find that the bridge shown in Fig. 13 is a false one, which is located in a garden in Kaifeng, Henan Province, built follow the famous

painting “Chhing-Ming Shang Ho Thu”, from which the timber arch bridge in China was discovered.



Fig.12 : Puqing Bridge



Fig.13: False timber arch Bridge

5 OTHER REMARKS

The timber arch bridge in China is a special bridge type. It represents an important facet of the rich and varied history of China and is inextricably intertwined with the technological, industrial and cultural development of China. From previous discussion, it can be seen that the two timber arch bridge types share the basic structure, but still there are more or less differences between them. What is the relationship between them is not very clear today. Some researchers said the technology of the extant Fujian-Zhejiang timber arch bridges was introduced from the ancient rainbow arch bridge when the capital of Northern Song Dynasty moved from Dongjing to Lin'an (now Hangzhou, Zhejiang Province) which means a new period in China, i.e., the South Song Dynasty (Mao 1986). Other researchers guessed that the existing Fujian-Zhejiang timber arch bridges can be developed independently and even have the possibility it was the originate technology of the timber arch bridge (Liu and Shen 2005).

Generally speaking, timber bridges are designed and built by bridge craftsmen. The inherited craftsmanship handed down from master to apprentice. Because many of them have a relation of father and son, thus the techniques have been translated generation by generation to form timber arch bridge family with stable characteristics in their construction technologies. However, there is only one or two such old bridge craftsmen good at timber arch bridges in Fujian Province today and no young person like to learn this technology because it is difficult to find an opportunity to build a timber arch bridge today, and this technology faces a lost tendency.

A timber bridge is easy to fire, rot and difficult to maintain, so the most timber arch bridges are vanishing with time. The extant timber arch bridges in Fujian-Zhejiang mountain area are most in serving as footbridge, many of them have been listed to Cultural Heritage Unit of local governments even some of them of the China government. However, there are still many of them under bad conditions with the time past.

For these extant timber bridges, source data revealing methods of their designing and erection are missing and the technical documentation of the structure is not available in most cases. Although many research works have been carried out on it, but most of them are cultural relics and architects, bridge engineers are busy in new bridges and those built bridges serviced in highway and railways, few of them have time and interests to research the ancient bridges. Thus, the structure behaviors and precision describe or engineering drawings are lack of these extant timber arch bridges.

The timber arch bridges are essence of architecture in China and part of the precious cultural heritage handed down from the ancient people. It is important in Chinese history of ancient bridge construction. We expect that more timber arch bridges will be maintained and protected under a further research works by many bridge engineers and other researchers encouraged and supported by governments.

It is known that timber structure is a kind of green structure. With advanced wood processing technique, engineered wood structure or wood composite structure expand the timber application in civil engineering as a structural material. It is also hoped that the research of the timber arch bridges in China can produce some innovative solutions of the modern wood structures.

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