

## Chinese Rainbow Bridges

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### Summary

“Qingming Festival on the River” is a famous painting from the Song dynasty. At the center of this painting a wooden arch bridge is depicted, which is called “Bian-He Rainbow Bridge”. It was built using a very special ancient technique, “woven” of straight wooden logs. This type of bridge does not appear in any other part of the world, and has disappeared from China several hundred years ago. 900 years later in 1980’s several dozens of ancient timber arch bridges were discovered in the mountain area of south Zhejiang and north Fujian Provinces. The structure of these bridges is suitable for large span and can cross river without any pier supports. These bridges are very similar to the Rainbow Bridge. In this paper the authors describe these bridges and their unique structures.

Keywords: Rainbow Bridge, timber arch bridge, lounge bridge, timber arch lounge bridge, woven timber arch bridge, woven timber arch-beam bridge

### 1. Introduction

“Qingming Festival on the River” is a famous Chinese painting drawn by Zhang Zeduan in the Song dynasty. It depicts a festival scene 900 years ago in Bianjing (now Kaifeng, Henan Province), capital of the Song dynasty. The scroll painting is 25.5 cm high and 525 cm long, which illustrates both sides of the River Bian-He and the street market during the Qingming festival. The painting is now being kept in Forbidden City Museum. In the painting, an exquisite bridge is depicted at the center and is called the “Rainbow Bridge” (see Fig. 1). “Woven timber structure” was applied to construct the bridge. The details of the construction are clearly revealed by the delicate painting skill and amazing craftsmanship.



Fig. 1 The Bian-He Rainbow Bridge

According to the book “Dream in Eastern Capital” by Meng Yuanlao in the Song dynasty, there were thirteen (13) bridges spanning across River Bian-He at that time. Three (3) of them were timber bridges without pier supports, and crossed the river like a rainbow. That might be the reason why they are named as “Rainbow Bridges”.

In 1126, Bianjing was occupied by the troops of Jin Kingdom. Lin’an (now Hangzhou) became the new capital of Southern Song dynasty. Between Jin and Yuan dynasties this type of bridges gradually disappeared from China. People thought that the secret of the construction of this type of bridge was lost. Many international researchers and scholars also

thought this unique construction which do not exist in the western society, would never have the chance to be seen in China.



Fig. 2 Rainbow bridge in Jinzhe Town

In 1999, NOVA of the United States organized a team of engineers to China. Under the supervision of Professor Tang Huancheng, the American engineers and their Chinese colleagues re-built a rainbow bridge using the ancient techniques (see Fig. 2). This bridge is located in Jinze Town, which is about 60 km west of Shanghai. The Americans team also produced a TV documentary “Secrets of Lost Empires - China Bridge” [1].

In the early 1980’s, Chinese researchers found a dozen of ancient timber arch bridges in the mountain areas of south Zhejiang and north Fujian Provinces. The structures of these bridges are quite similar to that of Rainbow Bridge. The result of these researches

is recorded in the book “Technology History of Chinese Ancient Bridges”, edited by Mao Yisheng and was published in 1986 [2, 3]. There are eleven (11) bridges recorded in this book, including six (6) in Zhejiang, four (4) in Fujian and one (1) in Gansu Province.



Fig. 3 Map of Zhejiang and Fujian province

Since 1996 a research team on timber arch bridges led by the second author of this paper had gone to the mountain areas in the Zhejiang/Fujian province for eight consecutive years. All together they inspected thirty-one (31) bridges in the Zhejiang Province and nineteen (19) bridges of Fujian Province. The local colleagues also provided additional information for another thirty-four (34) bridges in the Fujian Province [4]. It is believed that there are around one hundred (100) bridges of this type existing in that area (see Fig. 3).

In this paper following terms will be often used.

- 1) Bian-He Rainbow Bridge: the arch bridge depicted at the center of “Qingming Festival on the River”.
- 2) Woven timber arch bridge: the special structure of Rainbow Bridge.
- 3) Lounge bridge: the bridge with a lounge on its deck. There are about 300-400 bridges of this kind in the Zhejiang and Fujian Provinces.
- 4) Timber arch lounge bridge: timber arch bridge with lounge. It is a large scale bridge among the lounge bridges.

5) Woven timber arch-beam bridge: the special structure of timber arch lounge bridge.

## 2. Example of Timber Arch Lounge Bridges

### 2.1 The Oldest, Newest, and Longest Bridges

The oldest timber arch lounge bridge existed in last century was the Yeshuyang Bridge in the Taishun County, Zhejiang Province. It was built in 1454 and was demolished in 1965 due to the construction of a new road. It was 511 years old at that time [2].

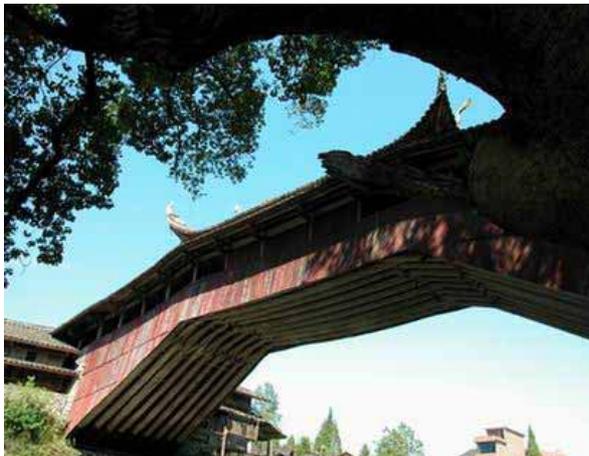
The bridge with the longest span was the Santan Bridge in the Taishun County, with a net span of 42 m. It is a record in the Chinese ancient bridges. Santan Bridge is 5 m longer than the existing Anji stone arch bridge in the Hebei Province. Santan Bridge was destroyed by a flood in 1950 [2]. The existing oldest bridge is the Rulong Bridge in Qinyuan County, Zhejiang Province, which was built in 1625. It is 28.2 m long, 5.1 m wide, and 19.5 m net span.

There are two existing bridges with the longest spans, and they are located in the Shouning County, Fujian Province. Luanfeng Bridge is 47.6 m long, 4.9 m wide. Yangxitou Bridge was built in 1967 and is 50.5 m long, 5.1 m wide. Both bridges have a net span of 37.6 m, and are similar to Anji Bridge. Yangxitou Bridge is the newest bridge, as there has no other bridge of this type constructed since 1967. There were six (6) new and renovated bridges project during the 1950's and 1960's.

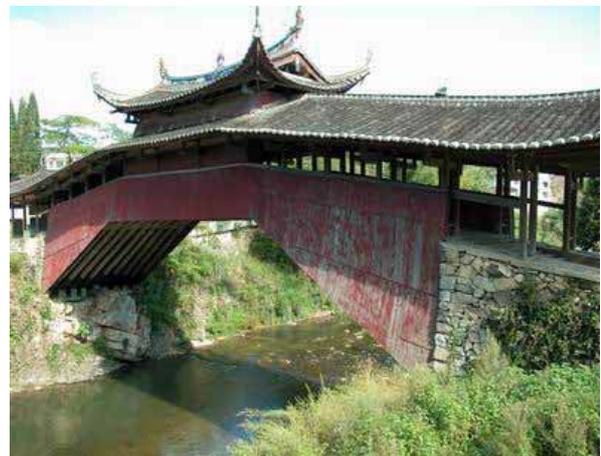
### 2.2 Sister Bridges Over Dongxi Stream

Near by the Sixi Town in Taishun County, Beijian and Xidong Bridges span over the Dongxi Stream. They are similar to each other and are called the sister bridges.

Beijian Bridge was built in 1674, and is 51.9 m long, 5.4 m wide and 29 m net span [2] (see Fig. 4). Xidong Bridge was built in 1746, and is 41.7 m long, 4.9 m wide and 25.7 m net span [5,6] (see Fig. 5).



*Fig. 4 Beijian Bridge*

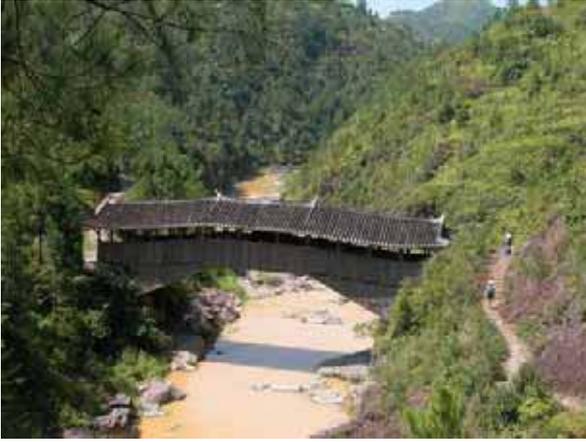


*Fig. 5 Xidong Bridge*

Both bridges are the most beautiful ones among the lounge bridges. Their lounges have Chinese traditional roofs covered with black tiles and curvy horn-like feature at the top pointing up into the sky. Both sides of the bridge are covered with overlapping red panel boards and serve as rain screens. The setting around the Beijian Bridge is extraordinary. There are two streams merged on the side of the bridge. Standing on one end of the bridge are two (2) thousand-year old camphor trees, with trunks over 2 m and shades over 10 m. From afar, there stand the Lion hill and the General peak. This sets an extremely colorful and well coordinated natural scenery consisting of the ocean blue sky, milky cloud, mountains, pure streams, green leaves, black roof tiles, and red panel boards.

### 2.3 Isolated Santiao Bridge

Santiao Bridge in the Taishun County was built in 1843, and is 32.0 m long, 4.0 m wide, 21.3 m net span, and 9.6 m elevated. During that time, it was situated in the main road between the Zhejiang and Fujian Provinces. As time goes by, this area is scarcely populated. The nearest village is half an hour of walking distance [5, 6] (see Fig. 6).



*Fig. 6 Santiao Bridge*

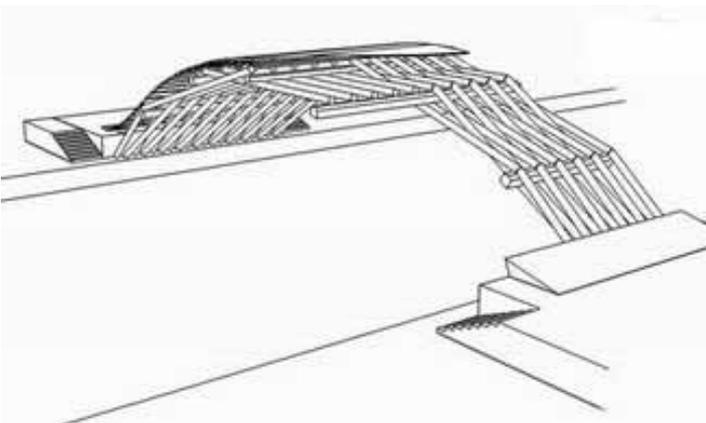
spirit in this so-isolated area. This harmony with the nature makes the writer feels the Santiao Bridge is the most beautiful one among the arch lounge bridges.

The structure of Santiao Bridge is simple, clear and logical. In view of modern structural mechanics it is almost perfect. It is a reflection of the superb craftsmanship in bridge building at that time. The original site of the Santiao Bridge had other construction of bridges, which can be dated back to 7th-century and has important significance in history of ancient bridge engineering.

## 3. Wonderful Structures of Bridges

Bridge engineers all know that structural members can withstand compression far more than bending. Therefore, the loading capability and span of arch bridges are better than conventional bridges. However, the difficulty is on how to effectively use straight logs to form the required arch! Nevertheless, the Chinese craftsmen already solved this challenge more than 900 years ago in building the Bian-He Rainbow Bridge.

### 3.1 Woven Timber Arch Bridge – Special Structure of Bian-He Rainbow Bridge



*Fig. 7 Structure of Woven Timber Arch Bridge*

Santiao Bridge is distant from the highway, and located at the bottom of valleys. Its architectural form is simple, but the grayish side panels are a historical proof of its withstanding of a hundred year of weathering. There is no spectacular coloring on the bridge except some white, dull gray and black color from the roof structure and tiles. It looks pure, natural and graceful. The size of the bridge blends in with the surroundings perfectly, it pierces through the water flowing through the streams, the boulders and cobbles stones scattering along the path. Walking along such ancient lane or standing on the bridge is like entering in a time tunnel, as one will see only things from hundred years ago. The vigorous vegetations give out another dimension of living

The structure of Rainbow Bridge was composed of two kinds of timber frames; one 3-segment frame and the 4-segment frame (see Fig. 7). The former had three components equal in length, one central round timber and two side timbers. The latter had two longer central timbers and two shorter side timbers. With the frames probably placed together, there were five transverse spaces between frame joints and timbers. Five girders were inserted into the spaces. They were beneath the joints and sat above the middle of timbers. The girders, joints and timbers were then tied together with

bamboo ropes to form an arch structure.

Bian-He Rainbow Bridge was composed of eleven (11) 4-segment frames and ten (10) 3-segment frames. The bridge was around 18.5 m in length, 4.2 m in height and 9.6 m in width [2]. When the arch was loaded, abutments on either side of riverbanks absorbed the generated horizontal thrust. In view of structural mechanics the timbers behaved not in bending but in compression. So this structure was a pure arch. Computer simulation approved this conclusion.

If we imagine the 3-segment frames and 4-segment frames are longitudinal fibers and the girders are lateral fibers, the method to construct the bridge structures is just like the “woven” technology. Professor Yang Hongxun proposed to call this type of structure “woven timber arch bridge”.

### 3.2 Woven Timber Arch-Beam Bridge – Special Structure of Timber Arch Lounge Bridges

The structure of timber arch lounge bridge is also composed of two kinds of frames, one 3-segment and the other 5-segment. The 5-segment frame has three longer central and side timbers, and two shorter corner timbers. When the frames are put together six transverse spaces are produced. Six transverse girders are used. This structure is quite similar to that of Rainbow Bridge. However, there are two differences between them. (1) The ends of timbers at joints are tenoned with girders, so ropes do not tie the girders, timbers and joints together. (2) There are two girders above the central timber of 3-segment frames, and will be balanced with the central timber in the 5-segment frames. This is a variation of a non-typical woven structure (see Fig. 8).



The timber arch lounge bridges are usually built at the bottom of valleys. The tip of the arch is several meters lower than the road. The banks of the river, the deck and the arch of the bridge form two triangular spaces. The deck timbers, side timbers of the arch and other components are used to construct strong trusses in the spaces. The side and corner timbers are woven structure and loaded by compression. But the central timbers are applied by bending loads. So the whole structure behaves like a hybrid of arch and beam. The authors propose to call it “woven timber arch-beam bridge”.

Fig. 8 Structure of Woven Timber Arch-Beam Bridge

## 4. Conclusions and Discussion

### 4.1 Conclusions

- 1) Bian-He Rainbow Bridge and the similar bridges existed in the Song dynasty and disappeared later due to the fading of Bianjing. So there was no longer this type of bridge built in that area.
- 2) Rainbow Bridge was a woven timber arch bridge. It was the most logical structure composed of straight timbers, and provided larger span and loading capability.
- 3) There are around hundred timber arch lounge bridges in the Zhejiang and Fujian provinces of China. Their structures are similar to Rainbow Bridge.
- 4) Timber arch lounge bridges are woven timber arch-beam bridges. They are suitable for long span bridges.
- 5) The arch lounge bridges in the Zhejiang and Fujian Provinces possess tremendous amount of historical, cultural, technological, and economical significance and value. They are the treasures of China and cultural heritages of the world.

## 4.2 Discussion

### 4.2.1 The Relationship Between Rainbow Bridge and Timber Arch Lounge Bridges

Rainbow Bridge and timber arch lounge bridges are all woven structures. So people are interested in their relationships. Many researchers think the Rainbow Bridge is the original root and timber arch lounge bridges are its successors. They believe in 12th-century many experienced carpenters migrated from north China to south China when the capital of Song dynasty was moved from Bianjing to Lin'an. They brought along the technology and built the woven timber bridges in Zhejiang Province. That was the beginning of the timber arch lounge bridges.

Others have doubts about the original invention of Rainbow Bridge. It was told that a prison guard invented the rainbow bridge. Was it possible that this guard could invent such a marvelous bridge without the related engineering experience and sample structure? On the contrary there exist hundreds of different kinds of bridges in Zhejiang and Fujian Provinces, from very simple beam bridges, continuous beam bridges, truss bridges, to complicated arch bridges. It seems that the timber arch lounge bridges were developed gradually step by step in the local area. The Rainbow Bridge and the likes, and timber arch lounge bridges were developed independently and concurrently. Or the former was the successor of the latter.

### 4.2.2 Why the “Woven Timber” Technique Has Not Been Applied to the Buildings?

Most of the ancient Chinese buildings were built with wooden material. The structures were composed of beams and pillars. Because of the limitation in length and in loading capacity of beams, it was impossible to construct large-scale hall without columns. The span of woven timber structure can reach at least 50 meters. If it were applied, a hall with several thousand square meters floor space could be built without any columns. How great this would be!

Structure plays an important role in the form of the architecture. Large dome-shape architecture can be formed with a series of arches connected around the circumference. It would have been a real revolution in the ancient Chinese architecture. However the arch technology was never excelled to this application for over 900 years of history. What are the reasons?

## Acknowledgement

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