Design Concept of the Twin River Bridges in Chongqing

Man-Chung Tang  
Chairman of the Board  
T.Y. Lin International  
San Francisco, CA, USA

Dr. Tang is a member of the US National Academy of Engineering and a foreign member of the Chinese Academy of Engineering. He received his Dr.-Ing. in 1955 and he has spent 40 years in the specialized field of bridge design and construction.

Summary

The Dongshuimen Bridge over the Yangtze River and the Qianximen Bridge over the Jialing River in Chongqing are located at the tip of the Yuzhong Peninsula. Together, they are called the Twin River Bridges. Both are double deck structures carrying four lanes of traffic on their upper decks and two transit tracks on their lower decks. The girders are steel truss structures with orthotropic plates and the towers are made of concrete. Aesthetics were carefully considered for the design of these bridges because of their visibility in the city and their neighboring landmarks.

Keywords: Long span bridges, partially cable-supported girder bridge, cable-stayed bridge, extradosed, steel truss, bridge aesthetics, Chongqing.

1. Introduction

With a population of 32 million, Chongqing remains one of the largest cities in the world. Its metropolitan area is bisected by two major rivers, the Yangtze River in the south and the Jialing River in the north. The municipality of Chongqing is comprised of three parts: the southern district, the northern district and the Yuzhong Peninsula in the middle, where the central business district is located. In recent years, several bridges have been built to facilitate traffic through these three regions of Chongqing. Despite these efforts to relieve congestion, the rapid growth of the City continues to outpace transportation planners’ traffic projections and the existing bridges are not sufficient to handle the ever-increasing traffic. In response to this problem, the city is planning to build approximately 500 km of transit tracks to reduce pressure on city roads in addition to erecting yet another two bridges.

The new Dongshuimen Bridge (Fig.1) will cross the Yangtze River, connecting the southern district to the Yuzhong District. The new Qianximen Bridge will cross the Jialing River, connecting the Yuzhong District to the northern district. A tunnel in the Yuzhong District will connect these two bridges, allowing both transit and road traffic from the southern district to flow through Yuzhong to the northern district without interruption. Both bridges will have four lanes of highway traffic as well as pedestrian paths on their upper decks and they will carry two tracks of transit on their lower decks. The Twin River bridges will belong to transit line number 6.

The two bridges will be strategically located at the tip of the Yuzhong Peninsula, connecting the central business district with both the newly developed Jiangbei business district in the north and the recreation quarter in the south bank of the Yangtze River. Notably, they will be situated next to two of Chongqing’s most important landmarks: the Hongyadong, is a typical...
ancient Chongqing building, and the Hu Guang Hui Guan, a 400-year old historic building group. Because of the bridges’ high visibility, aesthetics were an important consideration during the bridge type selection process.

In 2008, the owner held an international design competition to select the final design. More than 20 bridge schemes were submitted by consultant firms encompassing all types of bridges including girder, suspension, cable-stayed, arch, and extradosed bridges, and combinations thereof. The owner finally selected the partially cable-stayed girder bridge scheme proposed by the joint venture of Chongqing Communication & Research Institute and T.Y. Lin International. The joint venture had also submitted a suspension bridge scheme which, incidentally, was the runner-up to the partially cable-stayed girder bridge scheme. As the technical director for the joint venture, the writer was responsible for the conceptualization of both bridge schemes.

2. Bridge Type Selection

The configuration of the Dongshuimen and Qianshimen bridges had to satisfy aesthetic, geographic, and technical criteria. Because they were to be located between three city districts, they had to be harmonious with three disparate surroundings. They had to complement one another and they had to stand on their own. Finally, the bridges could not obstruct views of the city from various vantage points.

Navigational requirements and local geology demanded main span lengths of 445m and 340m for the Dongshuimen and Qianximen Bridges respectively. The lack of a side span at the Yuzhong side of the Qianximen Bridge limited the number of towers it could have. Both span requirements influenced the type selection process.

In addition, the bridge girder had to be at least 12m deep to accommodate transit tracks on its lower deck. Such a deep girder has to be a truss for two reasons: to offer transit passengers a more open view of the area and to increase the transparency of the bridges themselves.

Another key factor during type selection was that the city had just constructed two major arch bridges not far away: the Caiyuanba Bridge and the Chaotianmen Bridge. Therefore, an arch bridge was not a favorable choice.

The choice of a conventional cable-stayed bridge was discarded because it would obstruct one’s view of the city. A 340m span single tower cable-stayed bridge must have a tower protruding approximately 170m above the deck level. The bridge would be roughly 60m above normal water level so the total height of such a tower would be approximately 230m tall—taller than almost every building in the city. A conventional cable-stayed bridge would also have too many cables, further hindering one’s view of the city.
Finally, the choice of a regular girder bridge was also discarded because of the bridges’ relatively long spans.

Consequently, the owner decided that the bridges should be either partially cable-stayed girder bridges or suspension bridges for their relatively shorter towers and fewer cables. Both minimalist designs disturb the surrounding space less.

Keeping in mind the locations of the bridges in relation to the Yuzhong Peninsula, it was natural that the two bridges should be identical. Therefore, the writer conceptualized two schemes—a pair of suspension bridges and a pair of partially cable-stayed girder bridges.

3. Suspension Bridge Scheme

This scheme is comprised of two single tower suspension bridges with 496m main spans (Fig. 2). The side spans of both bridges are 250m long. They both have two planes of cables. The towers are 100m above the deck.

![Figure 2 A pair of Suspension Bridges](image)

On the Yuzhong Peninsula, where the rock formation is very fractured, it would be difficult to anchor the main cables in the soil, unless a large anchor block and a major tie back system to transfer the cable force deep into the ground was used. Because there are numerous buildings in the area, the tie-back anchors would compromise the foundations of these buildings. Therefore, conventional suspension bridges were deemed unsuitable for these two bridges.

Self-anchored suspension bridge scheme was also studied. A 496m span self-anchored suspension bridge is technically possible, despite its record-setting length. However, it would be very expensive. To build a self-anchored suspension bridge, the girder must be erected before the cables can be suspended. This would require placing costly temporary piers in the river. The busy river traffic and swift current during the high water season would pose a danger to any temporary intermediate supports due to possible ship collisions. Consequently, the idea of self-anchored suspension bridges was discarded.

To resolve this problem of anchorage, a special concept was introduced.

The transit tunnel that connects the two bridges runs under a street on the Yuzhong Peninsula. The tunnel is 600m long with a subway station in the middle. Instead of having to anchor the cables to a foundation in the ground, it is possible to extend the main cables of the two suspension bridges over the length of the tunnel with a pair of cables equal in size to that of the main cables. (Fig. 3) The two cables that run between the main cables are stressed and anchored to two large blocks, one at each end of the transit tunnel. The connecting cables are stressed to a force slightly higher than the maximum force in the main cables. In this way, the anchor blocks will always exert a compression force on the rock formation, which is preferable. The connecting cables run through a separate chamber underneath the transit tunnel. The chamber can be excavated and constructed simultaneously with the transit tunnel.
Because this cable chamber is directly underneath the transit tunnel, right-of-way issues cease to exist and the cost will be minimal.

Figure 3 Connecting the Main Suspension Cables through the Yuzhong Peninsula

Aesthetically, the pair of suspension bridges were attractive and compatible with one other. As well, they complemented the landscape and were transparent in elevation.

4. Partially Cable-Stayed Girder Bridge Scheme

Compared to the tower of a suspension bridge, the tower of a conventional cable-stayed bridge is typically twice as tall. In this scenario, while the span of the bridge may be reduced to 340m, its tower would still remain 170m above the deck. Such a tall tower would not complement the surrounding landscape. Furthermore, a conventional cable-stayed bridge has many cables, and obstructs views of the city. Therefore, conventional cable-stayed bridges are not suitable for this bridge site. In order to satisfy all design requirements and aesthetic expectations, a pair of partially cable-stayed girder bridges was selected. (Fig. 4)

Figure 4 The Partially Cable-stayed Girder Bridge Scheme

The concept of a partially cable-stayed girder bridge[1] has been applied successfully to the design of several medium-span bridges in China, most notably the Sanhao Bridge in Shenyang. While the spans of the Twin River Bridges are much longer, the girder depths of these two bridges, at 12m, are also much deeper. Thus, the span to girder depth ratio is comparable to that of the previously designed medium-span partially cable-supported girder bridges.

The minimum main span length of the Dongshuimen Bridge is 445m. Thus, the span to girder depth ratio is $445/12 = 37$. The minimum main span length of the Qianximen Bridge is 340m. Its span to girder depth ratio is $340/12 = 28.3$. These ratios are within the economic range of partially cable-stayed girder bridges.
The Dongshuimen Bridge will have two towers while the Qianximen Bridge will have one tower. The three towers are 100m high above the upper deck. Each tower of the Dongshuimen Bridge will carry six pairs of cables. The tower of the Qianximen Bridge will have seven pairs of cables. All of the cables will be located on a single plane on the center line of the bridge. The upper deck is an orthotropic steel deck with a minimum deck plate thickness of 16mm. The main floor beams are 2.00m deep. The lower deck consists of four longitudinal beams located directly under the rails. Transverse girders are 1.20m deep. The lower floor system is also an orthotropic deck with open ribs. The orthotropic deck serves as a platform next to the tracks. It acts monolithically with the lower chord of the main truss.

**Figure 5** Renderings of the Partially Cable-Stayed Girder Bridges

It is the desire of the owner that these two bridges are to be signature structures of the City. With a single plane of cables in the middle of the box girder, the towers can either be a diamond shape or an inverted Y shape. However, those tower shapes would not have been sufficiently distinctive to satisfy the aesthetic requirement. After extensive studies, the very special tower shape as shown was adopted.

The partially cable-stayed girder bridge scheme was selected by the owner for the final design. (Fig. 5)

### 5. Design Concept of the Partially Cable-Stayed Girder Bridges

Because a 12m deep girder is required to accommodate the transit tracks on the lower level, the main truss girder itself provides a relatively high capacity for carrying the loads. The concept of partially cable-stayed girder bridge, as described in [1], can be applied here with great advantage. The idea is to design a girder bridge, the load capacity of which is to be supplemented by cables. The cable forces are so selected as to provide what is needed to bring the total capacity of the bridge to the required level. Therefore, the cable forces can be assigned with relative freedom.

Fig.6 portrays the design procedure of a partially cable-stayed girder bridge. Fig. 6a illustrates a three-span girder under a uniform load. Fig. 6b demonstrates the bending moment capacity of the girder under the given load with the positive and negative bending moment capacities of the girder plotted. Portions of the girder do not have a sufficient capacity to resist the bending moment caused by the load on the girder. (See Fig.6c) To address this issue, a cable-stay system (Fig 6d) that will produce a bending moment capacity (Fig. 6e) to make up the difference must be employed.

There are many combinations of cable forces that can produce bending moments that will satisfy or exceed the demand requirements not assumed by the girder’s moment capacity. (See Fig 6f) It will be advisable to assign cable forces in such a way as to gain certain advantages
in fabrication and/or in construction. For example, to simplify construction of the girder, we can select a set of cable forces that will have the same vertical component. This will allow us to have one design for all cable anchorage points. Alternatively, we can assign the same force to all cables to simplify cable manufacturing.

![Diagram of girder and cable system](image)

Figure 6 The Concept of Partially Cable-Stayed Girder Bridge

A partially cable-stayed girder bridge is an economical solution in that it fully utilizes the capacities of both the deep girder and the stay cable system. In addition, a single plane of cables has a transparent appearance and satisfies the aesthetic criteria for this location.

6. A Beautiful Addition to the Bridge Capital of China

Since the opening up of China 30 years ago, bridge construction has been a focus of infrastructure developments there. In 1996, the City of Chongqing was separated from Sichuan province and became a special municipality, reporting directly to the central government. Chongqing has since become one of China’s most vibrant cities. The city’s rapid development has led to the construction of many new bridges. Indeed, Chongqing is often called the “Bridge Capital of China” because of its plethora and variety of bridges. Upon completion, the Dongshuimen Bridge and the Qianximen Bridge will be yet two more beautiful additions to this Bridge Capital of China.

References