Study on the History and Present Situation of Cable-stayed Bridge Structures in China

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Abstract. With the improvement of force mode, the development of material characteristics and technologies, the Cable-stayed Bridge structures are used more and more widely. In 1975, Yunyang Bridge, the first experimental Cable-stayed Bridge of China, was completed. In the following decades, China has greatly increased the span of bridges and the height of towers. During construction, the materials used to build bridge structures are more diverse and safer. In 2017, the Hong Kong-Zhuhai-Macao Bridge, representing the most advanced bridge-building technology in China at the time, was born. In this paper, the history of ancient Cable-stayed Bridges is firstly introduced. Then, several Cable-stayed Bridges which have great influence are researched, respectively. Finally, this paper compares Yunyang Bridge and Hong Kong-Zhuhai-Macao Bridge in-depth from three aspects: comparison of the construction scales, comparison of the construction materials and comparison of the cable technologies. The results show the progress of bridge industry in the past 42 years of China.

Keywords: Cable-stayed bridge structure; Hong Kong-Zhuhai-Macao Bridge; Yunyang Bridge.

1. Introduction

With the development of economy, the demand of people for convenient passage is increasing, and at the same time, the demand of people for cross-sea bridge is also becoming stronger and stronger, as it is more convenient for local people to travel in two areas. The cross-sea bridge will not only bring closer cultural exchanges between the two places, but also promote the development of tourism and increase the local income. In addition, the government and developers are also looking for a cost-effective, safe and fast building bridge. Therefore, a bridge with large span capacity, reasonable joint force and low cost has been designed, which is a cable-stayed bridge.

Cable-stayed Bridge is a kind of composite bridge structure system and composed of tower, beam and high-strength cable. The main beam is pulled diagonally across the pylon, which make the large span girder into a continuous beam on the elastic support, in order to reduce the bending moment in the beam. It differs from a traditional bridge in that it has stayed cables instead of the middle pier. Cable-stayed bridge has many advantages, such as it has a large span capacity, reasonable structural force, economical and beautiful, can cantilever assembly and has a wide adaptability, such as suitable for river width, water depth, rapids construction characteristics.

In this paper, the history of the Cable-stayed Bridges in China is described. Then, taking two bridges as examples, the paper compares the changes of cable-stayed Bridges in China in the past 50 years.

2. Development history of cable-stayed Bridges in China

Historically, the Cable-stayed Bridges evolved from Suspension Bridges. The history of the evolution of cable-stayed bridges shows that long time ago, people had the ability to suspend cables from pylons to support beams. China is one of the earliest countries in the world to have suspension Bridges, with a history of more than 4000 years. Suspend bridges often form an important part of a castle's defense system. In ancient times, every region or city had a wall on the edge, and there was a moat generally outside the ancient wall. And opposite the gate there was a bridge, which is convenient for people entering and leaving the city gates. In the event of an emergency, the gate was immediately

closed, and the bridge was hoisted up by ropes. This was to cut off the way to the gate so that the enemy could not get in [1].

For tropical Southeast Asia, and China's Sichuan region, their climate is warm, rainfall is larger, rivers and streams are more. There are a lot of rattan bamboo growing there [1]. Therefore, the local people built many cable-stayed Bridges using rattan and bamboo as raw materials. For both of these bridges, the cable does not bear the load of the bridge, but mainly transfers manpower through the flexible cable to lift or lower the bridge deck.

However, the difference between Cable-stayed Bridge and Suspension Bridge is that the static load of the suspension bridge is all borne by the suspension cable [2]. The stiffening beam produces internal forces only under the action of live load and temperature change. However, Cable-stayed bridge is a kind of girder bridge which is stiffened by effect of axial force [3]. The number and form of cables are various, the main beam supported by cables is elastic support state, so. cable-stayed bridge is a structure with rigid support and elastic support [4, 5].

With the development of bridge technology, Cable-stayed Bridges are gradually known by everyone because of their numerous advantages. Cable-stayed Bridges are also increasingly being used in projects that are extremely difficult to construct. With the rapid development of cable-stayed bridge in foreign countries, it also attracts the attention of bridge in China. Therefore, China built its first cable-stayed bridge.

Table 1. Data from five cable-stayed Bridges [6]

Bridge name	Province	Main span (m)	Meter wide (m)	Beam depth(m)	Tower height (m)	Completed year
Yunyang bridge	Szechwan	75.84	3.1	1.00	11.18	1975
Taipei Danshui River Bridge	Taiwan province	134	20	1.6	17.5	1977
Shantai Bridge	Szechwan	128	9.00	2.00	29.00	1980
Zhangzhen Bridge	Zhejiang Province	72	12.80	2.50	38.50	1983
Hongshui River Bridge	Guangxi province	96	5.60	3.20	26.60	1980

(1) Yunyang bridge

From the Table 1, it can be seen that the Yunyang Bridge is in Sichuan Province. Its main span is 75.84 meters, bridge width is 3.1 meters and beam height is 1 meter. The tower is 11.18 meters high. It was officially completed in 1975 and it is the prestressed reinforced concrete highway cable-stayed bridges. Every tower has three pairs of stay cables, which are composed of steel core cables and arranged in a radiating shape. A single box the main beam is about 1.0 m high. It is also the China's first experimental cable-stayed bridge [1].

(2) Danshui River Bridge

In 1977, Danshui River Bridge in Taipei was completed, which located in Taipei, Taiwan Province. From the Table 1, Its length is 1080 meter, of which main bridge is 402 meter in length and 20 meter in width. The depth of the bridge is 1.6m and tower high is 17.5m. The main bridge is a three-tower prestressed concrete cable-stayed bridge with a span of 2× 134m, which is connected by rotatable and telescopic hinges. What's more, it is multi-span cable-stayed bridge [6]. Taipei Danshui River Bridge is the first cable-stayed bridge of three - tower prestressed concrete in the Asia-Pacific region [1].

(3) Hongshui River

In 1980, Hongshui River Bridge in Guangxi was completed in 1981. Located over the Hongshui River in Laibin, Guangxi, its length is 398 m and span is 48 +96 +48 m. Its main beam section is single box double chamber. From the Table 1, Beam height is 3.2m and tower height is 26.6m. Main spin is 96m and meter wide is 5.6m. The cables are divided into inner, middle and outer groups, which are arranged in parallel and symmetrically on both sides of the cable pylon [6]. In China, the first sign that prestressed concrete railway cable-stayed Bridges can be built is the Hongshuihe Bridge in Guangxi [1].

(4) Lizhou-Shanghai Nanpu Bridge

In 1991, China built the Lizhou-Shanghai Nanpu Bridge, which was the first time China built a long-span cable-stayed bridge of more than 400 meters. The Nanpu Bridge is a cable-stayed bridge with double tower and double cable plane. The main bridge adopts the composite beam structure of steel beam and reinforced concrete precast plate. Main bridge's tower is a broken line H-type reinforced concrete structure. The two sides of each tower are connected to the main beam by steel cables, and the cable surface is arranged in a fan shape. The Nanpu Bridge is 8364 meters long and this main bridge is 836 meters long. The bridge tower is 155 meters high. There are 22 pairs of cables on each side of the bridge tower [1].

(5) Zidong Bridge

The Zidong Bridge in Nanhai, Guangdong Province, which was built completely in 1997, pioneered the construction of concrete-filled steel tube cable-stayed Bridges. Zidong Bridge's span in Nanhai, Guangdong Province is 69 +140 +69 m, with single cable surface of twin towers. This beam height is 3m, the width is 25.5m, and the tower column is also using concrete filled steel tube, the pipe diameter is 1.83 m. This bridge is the first concrete filled steel tube cable-stayed bridge in the world [1].

(6) Yangtze River Bridge

Yangtze River Bridge in Wuhu, Anhui Province was completed in 2000. The bridge is a double-deck railway bridge, the railway bridge for the I double line, 10 521 m long; The highway bridge is four lanes and 5 681 m long; The main bridge is 2 193 m long, and its span is 120 +2 ×144 +2 ×(3 ×144)+(180 +312 +180).+2 × 120m.It also has double tower and double cable surface steel truss girder cable-stayed bridge [1]. Wuhu Yangtze River Bridge has made a series of creative achievements in new structure, new material, new technology and new technology [1].

(7) Hong Kong-Zhuhai-Macao (HKZM) Bridge

In 2017, HKZM Bridge, the three navigable Bridges of the main bridge are constructed completely and all cable-stayed Bridges. Its main tower is about 3,000 tons of self-weight. About 7,000 tons of beam surface tension a number of 8 to 23 tons of ultra-high strength parallel wire giant cable-stayed cables. Taking Qingzhou Fairway Bridge as an example, it is a cable-stayed bridge of steel box girder with two towers and two cable faces. It adopts semi-floating system and spans 1,150 meters. The tower adopts a frame tower with double columns 163 meters high, with 14 pairs of cable stays.

3. Comparison of Yunyang Bridge and HKZM Bridge

In 1975, China builds the first experimental cable-stayed bridge, Yunyang Bridge. In 2017s, Hong Kong-Zhuhai-Macao Bridge which is built by China had become the world's longest sea-crossing bridge at that time. During the 42 years, China learns from the experience of foreign countries in building cable-stayed bridges. China also has improved its technology in automatic control technology and information technology and super-long span cable-stayed bridge.

(1) Construction scale comparison

From the Table 2, the Yunyang Bridge and the HKZM Bridge have different amount of span and tower. The bridge span of Yunyang Bridge is 75.84 m and HKZM Bridge is 1150m. The tower height of Yunyang Bridge and HKZM Bridge are 11.1m and 163m respectively.

This is because the length or width of the bridge is required according to the different geographical location of the bridge and the different environment. What's more, Yunyang Bridge is prestressed

reinforced concrete highway cable-stayed and HKZM Bridge is cable-stayed bridge with steel structure, which has longer bridge span than Yunyang Bridge [7, 8]. Thus, steel structure cable-stayed bridge is selected on HKZM Bridge. Reinforced concrete cabled-stayed bridge is considered by lower bridge span and the government's need for low cost and expense [4].

Table 2. Comparison of span and tower height data of two cable-stayed Bridges [6]

Name	Yunyang Bridge	HKZM Bridge
Bridge span	75.84m	1150m
Tower height	11.1m	163m

(2) Construction materials comparison

Yunyang Bridge is a prestressed reinforced concrete cable-stayed bridge, which built on the river.

There are three reasons why Yunyang Bridge is a prestressed reinforced concrete cable-stayed bridge. Firstly, prestressed reinforced concrete cable-stayed bridge save steel and reduce the material cost of the bridge [9]. Secondly, compared with the steel bridge, the maintenance cost of prestressed reinforced concrete cable-stayed bridge is relatively low and the driving noise is small [10]. Finally, compared with reinforced concrete Bridges, weight and building height of prestressed reinforced concrete cable-stayed bridge are smaller and lower, and their durability is due to the use of high-quality materials and elimination. Qingzhou Navigation Bridge is a steel box girder cable-stayed bridge, which across the sea.

There are four reasons why Qingzhou Navigation Bridge is a steel box girder cable-stayed bridge with two towers and two cable faces. Firstly, the size of the steel box girder cable-stayed bridge beam is small. Secondly, the steel box girder cable-stayed bridge has a large crossing capacity [9]. Thirdly, the cable-stayed bridge with steel box girder is less restricted by the clearance under the bridge and the elevation of the bridge deck. Finally, the cable-stayed bridge with steel box girder has high wind resistance stability. Therefore, according to different situations, different bridges have been built using different structures and materials, as show in Table 3.

Table 3. Material comparison of two cable-stayed Bridges [4, 8, 9]

Name	Yunyang Bridge	HKZM Bridge
Construction materials	Prestressed reinforced concrete cable-stayed bridge	Steel box girder cable-stayed bridge with two towers and two cable faces
Advantages	1) Save steel 2) low cost of material of the bridge; 3) low maintenance cost 4) small driving noise 5) Smaller weight 6) low building height	1) small size of the beam 2) large crossing capacity; 3)less restricted by the clearance under the bridge and the elevation of the bridge deck; 4) high Wind resistance stability

(3) Technological comparison of stay cables

Yunyang Bridge has three pairs of stay cables in each tower which are composed of steel core cables. HKZM Bridge has super-high strength parallel wire giant cable-stayed cable. There are two reasons why it chose super-high strength parallel wire giant cable-stayed cable. Firstly, the cable body part is made of high-performance materials, which becomes a new cable with excellent anti-corrosion ability. Thus, it can increase in service life. Secondly, it uses the new materials and new technology. What's more, cable system used steel wire strength level of 1770MPa, as shown in Table 4.

Table 4. Technological comparison of stay cables [8 11]

Yunyang Bridge	HKZM Bridge

Three pairs of stay cables in each tower are composed of steel core cables	Super-high strength parallel wire giant cable-stayed cable 1) The cable body part is made of high-performance materials, which becomes a new cable with excellent anti-corrosion ability; Increase in service life 2) The use of new materials, new technology, cable system used steel wire strength level of 1770MPa

4. Conclusion

Cable-stayed bridge technology has developed rapidly in China since the 1970s. In 1975, Yunyang Bridge, first experimental cable-stayed bridge, was built in China. In 2017, the HKZM Bridge, was completed. China has overcome difficulties in building materials, security and stability. These are also the technical differences between the Yunyang Bridge and the HKZM Bridge. This paper draws the following conclusions from the study of Cable-stayed Bridges.

(1) Cable-stayed bridges are derived from suspension bridges and suspend bridges often form an important part of castle defense system in ancient times. The length of the beam depth and tower heigh was gradually getting long during the 42 years. China has built many historic Bridges in 42 years. For example, Taipei Danshui River Bridge is the first three - tower prestressed concrete cable-stayed bridge in the Asia-Pacific region and so on.

(2) In 42 years, China has improved the materials, stability and span of cable-stayed Bridges. Take the Yunyang Bridge and the HKZM Bridge as examples, The span of the HKZM Bridge is 15 times that of the Yunyang Bridge and the tower height of the HKZM Bridge is about 14 times that of the Yunyang Bridge. In terms of materials, the HKZM Bridge is Steel box girder cable-stayed bridge with two towers and two cable faces, which has larger crossing capacity and higher Wind resistance stability. However, Yunyang bridge is prestressed reinforced concrete cable-stayed bridge, which save steel and has low cost of material of the bridge. One focus is on saving cost, the other on improving technology.

(3) The construction process of cable-stayed bridge will adopt more automatic control technology and information technology. The information construction technology is used to monitor the data analysis and processing. Environmental protection and sustainable development will become the main trend of cable-stayed bridge construction. For example, for a bridge across the sea, several aspects need to be considered. Firstly, whether the construction process is shallow. Secondly, after the bridge is completed and opened to traffic, vehicles can bring tire pollutants and car exhaust. Thirdly, in case of a traffic accident, the pollution caused by the leakage of dangerous products to the shallow sea ecology.

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