Structural Analysis and Application of Long Span Suspension Bridge

Wenrui Liao *

Department of Civil engineer University of Nottingham Ningbo in China

* Corresponding Author Email: biywl23@nottingham.edu.cn

Abstract. The construction of long span bridges can facilitate people's travel. According to the data of the number of long span bridges, suspension bridges have become one of the best choices for long-span bridges. How to better design long-span Bridges has become the focus of attention. The main research topic of this paper is the structural design and case analysis of long span suspension bridges. Firstly, the design requirements and principles of suspension cables, beams, towers and piers of long-span suspension bridges are analyzed. Then, two cases of long-span suspension bridges are used to illustrate the design defects and key points. The conclusion shows that safety, economy and applicability should be considered in the design of long span suspension bridges. In the actual design of the bridge, it should also be paid attention to the natural environment and local characteristics. It is hoped that this paper can provide some help to the design and development of long span suspension bridges.

Keywords: Long span suspension bridge; structure design; structural analysis.

1. Introduction

With the development of society, the facilitation of traffic has become a more and more concerned issue. In order to facilitate people's travel, it is necessary to complete long-span bridges to across the sea, rivers, mountains and other areas. The long-span bridge refers to a bridge with the porous span of more than 100 meters and the single-hole span of more than 40 meters [1]. Suspension bridge refers to a bridge with cables suspended and anchored on both sides through a cable tower as the main load-bearing member of the superstructure. Compared to other bridge structures, suspension bridge can use less material to cover longer distances. And it can be built high enough to allow boats to pass underneath and across valley. Therefore, the suspension bridge has become one of the best choices for long span Bridges.

Long span suspension bridges are an important technical challenge in bridge engineering, they use the main cable to bear the main load and transfer the load to the tower and eventually to the foundation through the suspension cables. The overall design concept includes bridge site selection, bridge type comparison selection, and structural system selection and so on. In the selection of bridge site, the factors such as geological conditions, climatic conditions and navigation requirements should be considered comprehensively. When comparing bridge type, it is necessary to make comprehensive analysis according to span, load, cost and other factors to determine the optimal bridge type. In the selection of structural system, the safety, economy and aesthetics of the bridge should be guaranteed [2]. The main research direction of this paper is the structural analysis of large-span suspension bridges, such as suspension cables, beams, towers, piers, and some cases of long-span suspension bridges. The purpose is to provide data and case analysis for the design of long-span bridges what is used to solve some difficulties in the way of design and improve the construction efficiency of large-span bridges for solving the difficulty of across the sea, rivers, and mountains.

2. Structural Analysis of Long Span Suspension Bridge

2.1. Suspension Cable

As the main load-bearing component of suspension bridge, the stress state of suspension cable is very important to the safety and stability of the whole bridge. Therefore, the stress analysis of the suspension cable is the key link in the design of the long-span suspension bridge, which needs to consider the comprehensive influence of many factors.

First of all, it is necessary to consider the characteristics of the suspension cable itself, including the elastic modulus of the material, the section area and so on. These factors directly affect the mechanical performance and bearing capacity of the suspension cable. For example, when the suspension cable is subjected to tension, the larger the interface area, the stronger the bearing capacity [3]. Secondly, it is necessary to consider the interaction between the suspension cable and other components such as the bridge tower and the suspension cable. In suspension Bridges, suspension cables are connected to the bridge floor by suspension cables, while the bridge towers provide support and fixation. When the bridge floor is subjected to load, the load is first transmitted to the suspension cable through the sling, and then transmitted to the bridge tower. In this process, the stress of the suspension cable is affected by the interaction between the components. It is necessary to analyze and calculate according to the detailed data to get the appropriate scheme. In addition, the force analysis of the suspension cable also needs to consider the influence of external factors, such as wind load, temperature and so on [3]. Because suspension bridge is a flexible structure, which is very sensitive to wind load. The magnitude and direction of wind load will affect the stress state of the suspension cable. Thermal expansion and contraction caused by temperature change will also affect the prestress and stress state of the suspension cable.

For the stress analysis of the suspension cable, a variety of methods such as elasticity theory, perturbation theory, and finite cloud analysis can be used according to the specific situation, and accurate and effective stress analysis can be obtained to provide important reference for the design, construction and operation of the bridge.

2.2. Bridge Beam

As one of the important components of suspension bridge, the beam design should follow the three principles of safety, economy and applicability which are showed in Table 1.

Table 1. The three principles of beam design.

NO.	Principle	Explain
1	Safety	Strength and stability
2	Economy	Reduce the amount of materials and construction costs
3	Applicability	The design should be adapted to the layout and use

The appropriate beam type should be selected according to factors such as bridge span, load requirements and construction conditions. Common beam types are rectangular beams, I-beams and box beams. Rectangular beam is a suspension bridge with large flexural stiffness, which is suitable for bearing large loads, and is often used in short-span bridges. The I-beam has good mechanical performance and stability, which is suitable for medium-span suspension bridges, and is often used in urban cross-river bridges. The box beam has the characteristics of high torsional stiffness, which is often used in special layout or complex force suspension bridges, such as some long-span suspension bridges across rivers or mountains.

Static analysis and dynamic analysis are generally used to analyze the beam. By calculating the internal force and deformation of the beam under static load, the bearing capacity and safety performance of the beam are evaluated [4]. Then consider the response of wind, snow, earthquake and other dynamic loads to improve the evaluation of the beam.

The structural analysis and design of the beam are many aspects, which need to consider the design, construction, materials, maintenance and other links. As for the beam construction, material selection, maintenance and management are not the focus of this article, which will be ignored here.

2.3. Tower and Pier

For the towers and piers of long-span suspension Bridges, the design principles are consistent with the principles of the above beams, so that safety, economy and applicability need to be considered.

But beyond that, the tower needs to consider its visual requirements and be in harmony with its surroundings. The pier needs to consider environmental factors such as geological conditions.

Towers are usually made of reinforced concrete or steel. Due to the height of the tower, the effect of wind load needs to be considered. Measures such as setting wind support and adding dampers can be taken to resist wind. The structure of the tower is generally divided into rigid structure, truss type and mixed type, and they have their own characteristics. Rigid frame is equipped with a strong transverse beam to enhance the lateral stiffness. The truss type is formed by several diagonal rods crossing, but the construction is generally difficult, and it is often applied to steel bridge towers. The hybrid type combines the characteristics of rigid frame type and truss type, which is not only bright and simple, but also improves the function and economy of the tower.

The types of piers include solid pier, hollow pier, and reinforced concrete pier and so on. In addition to considering the force analysis, the design needs to consider the geological conditions, groundwater level, soil properties, etc., but also need to be selected according to the specific situation of pile and foundation. The design of towers and piers, as mentioned above, requires multiple considerations, through scientific design and optimization, to ensure the tower. Security and stability of pier.

3. Case Study of Long Span Suspension Bridge

Nowadays, more and more long-span suspension Bridges are built, and the span is longer and longer. As shown in Table 2, there are 10 well-known long-span suspension bridges. This paper mainly studies on the general situation and design analysis of two long span suspension bridges, including Tacoma Narrows Bridge and Jinsha River Bridge.

Table 2. 10 well-known long-span suspension bridges.

Name	Time	Span (m)	Location
Akashi Kaikai Bridge	1998	1991	Awaji Island, Kobe, Japan
Zhoushanxi Houmen Bridge	2009	1650	Zhoushan, Zhejiang Province, China
Great Belt Bridge	1998	1624	Denmark
Sancha Rock Bridge	2006	1577	Changsha, China
Runyang Yangtze River Bridge	2005	1490	Jiangsu, China
Nanjing Yangtze River fourth Bridge	2012	1418	Jiangsu, China
Humber Bridge	1981	1410	America
Jiangyin Yangtze River Bridge	1999	1385	Jiangsu, China
Verrazano Bridge	1964	1298	America
Golden Gate Bridge	1937	1280	America

3.1. Tacoma Narrows Bridge

The Tacoma Narrows Bridge is a famous suspension bridge in Tacoma, Washington, United States, also known as the "Wind Bridge" or the "Dancing Gertie" [5]. As shown in Fig 1, the bridge floor is shaking.

Fig 1. Twisty sponge bridge, Tacoma Narrows Bridge [6].

Construction of the bridge began in 1938 and lasted two years, opening to traffic in 1940. At 1,810 meters long and 12 meters wide, it was the third largest suspension bridge in the world at the time, after the Golden Gate Bridge and the George Washington Bridge, and cost a whopping $6.4 million [5]. However, just four months after opening to traffic, the Tacoma Gap Bridge collapsed due to wind-induced vorticity. The incident shocked the global engineering community and became a typical case of failure.

The environmental cause of the collapse of the Tacoma Bridge was the vortex vibration caused by Karman Vortex Street. When the wind blows over the bridge, it will form vortices on the lee side of the bridge, and these vortices will constantly generate and fall off, resulting in a periodic force on the bridge. When the frequency of this force is close to the natural vibration frequency of the bridge, it will cause resonance, causing the amplitude of the bridge to increase, and eventually cause the bridge to collapse [7].

But the main causes of the Tacoma Narrows Bridge collapse were design flaws and material quality issues. This paper focuses on the analysis of design defects. The original plan was to use 25 feet of steel truss girder, but Moissev, who is the famous architect of the Golden Gate Bridge, suggested using 8 feet of steel girder instead. His theory of elasticity suggested that this design would increase the stiffness of the main cable, thus better transferring energy to the bridge tower and anchoring. And make the steel beam narrower, not only make the bridge more elegant, with ornamental. And it reduces construction costs. However, the main span length of the bridge is too short, which leads to the resonance of the bridge deck under the action of wind. Moreover, the designer ignored the narrow width of the bridge deck, which limited the flow of wind and increased the pressure of wind on the bridge deck. It turns out that an 8-foot beam isn't enough to support the wind [8].

The Tacoma Narrows Bridge accident has reminded engineers that various factors must be fully considered in the process of bridge design and construction, especially the influence of natural factors such as wind power. After the accident, aerodynamic and resonance experiments were also made compulsory in architectural engineering, and all Bridges built since then have had to pass rigorous mathematical analysis and wind tunnel testing.

3.2. Jinsha River Bridge

Jinsha River Bridge is an important bridge located in Yunnan Province, China. Its design is full of engineering innovation and challenges. As shown in Fig. 2, the bridge is a long-span highway suspension bridge connecting mountains to mountains. The bridge, which spans the Jinsha River and connects traffic on both sides, is of great significance in promoting regional economic development and improving people's livelihood.

Fig 2. Jinsha River Bridge [9].

The design difficulties of Jinsha River Bridge are as follows: (1) Poor geology: steep terrain on both sides and narrow construction site; the vertical height gap between the route and the ground is large; the rock layer has high strength. (2) Bad climate: The Bridge is located in the northwest edge of the Yunnan-Guizhou Plateau, with high ultraviolet irradiation intensity and complex wind environment. (3) The bridge crosses the reservoir and has high environmental protection requirements.

This paper analyzes its characteristics from the aspect of design. (1) Structural innovation: Jinsha River Bridge adopts the main beam structure of plate girder combined with stiffened beam, welding the steel trusses and orthotropic steel bridge panels together. This structure not only increases the stiffness and strength of the bridge, but also reduces the weight of the bridge, reduces the material consumption, and improves the durability and wind resistance of the bridge. (2) Anchoring structure: The Bridge adopts tunnel anchoring structure, dispersing the strands of the main cable into the anchor body, and fixing it in the anchor plug body through the prestressed anchoring system. This structure makes the main cable replaceable, prolongs the service life of the bridge, reduces the occupation of the ground, and protects the local ecological environment. (3) Central buckle structure: The Jinsha River Bridge adopts a flexible central buckle structure to connect the two ends of the main cable together to form a closed ring structure. This structure balances the internal force of the main cable, reduces the deformation of the main cable, and improves the safety and comfort of the bridge. (4) Environmental protection design: Environmental protection factors are fully considered in the design process of the bridge, and environmental protection materials and processes are used to reduce the impact on the surrounding environment. At the same time, the design of the bridge also takes into account the future expansion and renovation needs, leaving enough room for future development [10, 11].

To sum up, the design features of Jinsha River Bridge are mainly reflected in structural innovation, anchoring structure, central buckle structure and environmental protection design, etc. These features make the bridge have a high degree of safety, durability and environmental protection, and also reflect human innovation and wisdom in engineering technology.

4. Conclusion

This paper mainly studies the design of long-span suspension Bridges, and draws the following conclusions through analysis and examples: The design of long-span suspension bridges should consider three principles, namely safety, economy and application. According to these three principles, suitable types and connection modes are selected for suspension cables, beams, towers and piers. In addition to the three principles, it is also necessary to consider the actual situation of the bridge, such as the influence of natural factors such as wind, snow, and temperature, and the order of the three principles, safety should be put in the first place. If not considered, it will have a huge impact on the bridge, leading to the collapse of the bridge, which will bring serious losses. Although the data in this article is limited, it does not take into account the treatment of various situations. It can still help with the design of long span suspension cables.

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