The development and evolution of bridge in Chongqing China

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Abstract

In this paper, the development and evolution of bridge in Chongqing and around the world are summarized particularly. Besides, the categories of bridges, the development of bridge design theories as well as the breakthroughs of bridge construction with the passage of time are also introduced systemically. With the introduction of the historical stone-arch bridges, the recent reinforced concrete slab bridges, modern pre-stressed concrete bridge, various arch bridges, suspension bridges and cable-stayed bridges, the prosperity and progress made by human beings in the process of transformation of nature are gradually revealed in this paper, the development and evolution of bridge is also revealed with the introduction of new techniques. The construction of bridge promotes the economic development and strengthens the connection of different areas, brings a booming market. The role of mechanics in bridge design is analysed and the development of Chongqing bridges can also be experienced in this paper. Bridge is not only a construction but also the creator of the soul of a city, showing the fighting spirit and braveness of a generation.

Keywords: Chongqing, Bridges, Development, Evolution model

1 Introduction

Bridge is a construction built to overcome natural or artificial obstacles. It usually comprises of five big parts and five small ones. The big parts refer to superstructure and substructure of bridge span that bears the load of cars and other vehicles. They assure the safety of bridge structure including (1) bridge span structure (also called bridge opening structure or superstructure), (2) support system, (3) bridge pier, bridge abutment, (4) cushion cap, (5) pile foundation [1]. The five small parts refer to those directly related to the service function of bridge, which used to be called bridge floor structures including (1) bridge floor pavement, (2) waterproof and water drainage structure, (3) bridge railing, (4) expansion joint, (5) lighting [2]. Bridge is also part of a road. From technologic perspective, the bridge development can be divided into ancient bridge, early modern time bridge and modern bridge [3].

Before 17th century, the ancient bridges are usually made of wood and stone, and accordingly, there were wooden bridge and stone bridge [4-6]. Bridge construction in the early modern times speeds up the rising and developing of bridge theories. In 1857, based on the precious researches on arch theories, statics and mechanics of materials, St. Venant put up a more comprehensive theory about girder theory and torsion theory. Meanwhile, theories about continuous girder and cantilever girder were also brought up. The development of these theories promotes the development of truss, continuous girder and cantilever girder. Modern bridges can be divided into pre-stressed rebar concrete bridge, the rebar concrete bridge and steel bridge.

The construction of bridge promotes the economical development and strengthens the connection of different areas, brings a booming market. The role of mechanics in bridge design is analysed and the development of Chongqing bridges can also be experienced in this paper. Bridge is not only a construction but also the creator of the soul of a city, showing the fighting spirit and braveness of a generation. Hence, it is very necessary and significant to investigate the development and evolution of Bridge.

Chongqing, which is honoured as a city of water and mountains, has to largely depend on bridges to connect rivers and hills. Because of various kinds of mountains and rivers, every connection must rely on innovation of bridge construction techniques. Chongqing bridges have outnumbered other cities and its construction numbers and difficulties are not a frequent sight around the world. So, study the development process of bridges at Chongqing has its scientific and social value. Based on the above reasons, this paper mainly generalizes the development of bridges in China and around the world.

2 Evolution of Chongqing bridges from a historical view

Because of the special terrain, bridges at Chongqing city play an important role in connecting mountains with rivers and thus improve the traffic. At 2005, Chongqing is also identified as the only “City of Bridges” by Mao Yishen Bridges Committee. Bridges at Chongqing have reached the number of 4900. Among all bridges, there are

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stone arch bridges with long history, magnificent steel and suspension bridges which across Yangtse River. Chongqing has a long history of bridge construction and the wisdom of its people is also well reflected in nature transformation and transport improvement. Because of too many valleys, rivers and rich sources of stones with high quality, many stone arch bridges were built in history and some of them are classic ones. Shiji Bridge, which is also called Guangji Bridge, located in the west part of Rongchang County and cross Laixi River. Shiji Bridge was built in AD 1050 when Wen Boyan, a chancellor in Song dynasty, named it Siji Bridge, which is the earliest bridge in record at Chongqing. At the end of Qing dynasty, for the consequence of Taiping Rebellion, salt in Sichuan has to be transported to Hubei Province, in which Siji Bridge provided a good guarantee. After that, it was honoured as the safeguard of east Sichuan Province by Majesty Cixi and earned its reputation.

FIGURE 1 Shiji Bridge

Dragon and phoenix Kezhai Bridge, which was built in Yuan dynasty, lies to 25 km from west part of Xiushan County and cross Pingjiang River. The bridge is oriented north and south and composed of six stone and wood arches. It is 58.2 meters long and 8.95 meters high. The bridge heads are doorways made up of blue bricks and gable walls and there are seven and ten steps respectively at each side. Kezhai village lies in west and cottages in east of bridge. It is the connecting road for villages Qingxi, Longfeng and Tangao and also serves as a place for divine activity for local Tujia nationality.

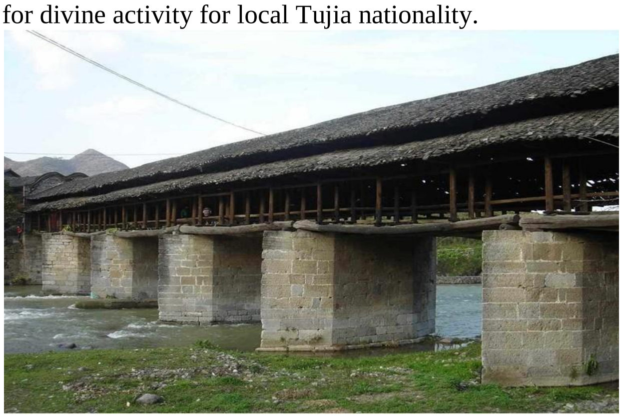

FIGURE 2 Kezhai Bridge

Except for the ancient stone arch bridge, there are still distinctive rope bridges at Ningchang, Wuxi County among all old bridges of Chongqing. People in Wuxi County are proud of Ningchang because the most glorious moment in the history of Wuxi County was created here. Back then, the people who used to live in deep mountains enjoyed great prosperity and richness for salt manufacturing there. With a history of over 4000 years, salt manufacturing at Ningchang is honoured as the place where the manual workshop in the world started. Thanks to the prosperity at ancient time, the rope bridge at Ningchang came into being.

FIGURE 3 Rope Bridge at Ningchang, Wuxi country

The construction of bridges at Chongqing mainly depends on the needs of city road construction. Less than 100 bridges with short spans are widely spread and most of them are arch ones. The most significant bridge must be Hualong Bridge built in 1930 since it is the first road stone arch bridge in Chongqing.

FIGURE 4 Hualong Bridge

Besides, there is Number One Bridge, which is the earliest and greatest one in scale. It was a five-span 16m rebar concrete girder bridge that was built in 1940s.

After the foundation of PRC, people in Chongqing made the most of their talents and abilities to construct many cross-river bridges with large span and high technology, seven of which are most representative ones. Baishatuo Bridge, which was built in 1959, is the first cross-river bridge in Chongqing. Niujiaotuo Jialing River Bridge, which was built in 1966, is the only steel truss girder bridge in southeast China.

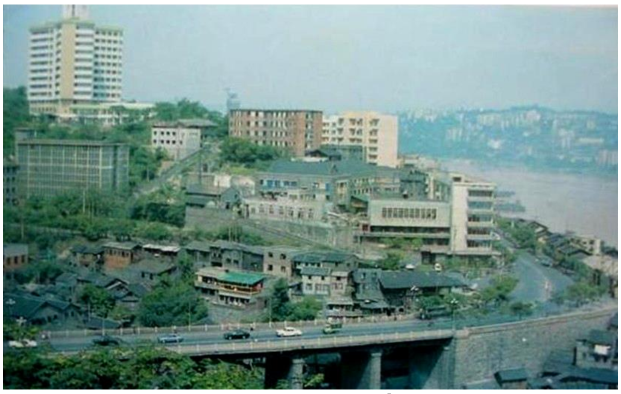

FIGURE 5 No.1 Bridge

Chaoyang Bridge at Beipei district, which was built in 1969, is the only double chain suspension bridge in China; Tangxihe cable-stayed bridge, which was built in 1975 at Yun'an, a small town in Yunyang County, is the first cable-stayed bridge in China. It marks the beginning of cable-stayed bridge construction in China. Shibanpo Yangtse River Bridge, which was the last work of Mao Yishen, was a prestressed concrete T-shaped rigid frame bridge built in 1980. Shimen Bridge, which was built in 1988, was the single tower and single plane cable-stayed bridge with the greatest span in China. Chaotianmen Bridge, which was built in 2009, was honoured as the "number one" steel trussed arch bridge in the world.

FIGURE 6 Baishatuo Bridge

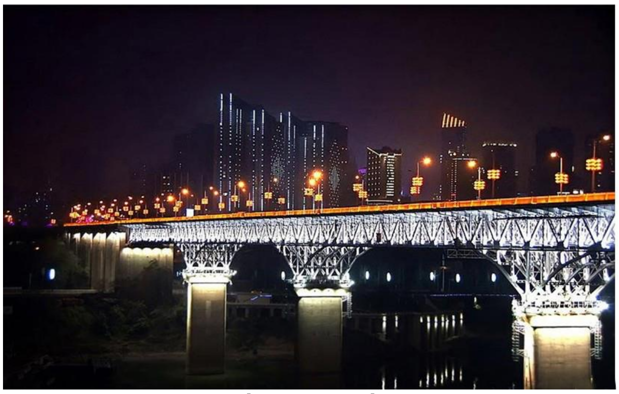

FIGURE 7 Jialing River Bridge at Njiaotuo

FIGURE 8 Chaoyang Birge at Beipei

FIGURE 9 Shibanpo Bridge

FIGURE 10 Tangxihe Cable-stayed Bridge at Yun'an, Yunyang County

FIGURE 11 Shimen Bridge

3 The development and evolution of bridges at Chongqing from economic and technological view

Chongqing, which is honoured as a city of water and mountains, has to largely depend on bridges to connect rivers and hills. Because of various kinds of mountains and rivers, every connection must rely on innovation of bridge construction techniques. Before modern times, most bridges at Chongqing were arch ones because of the underdeveloped economy and construction techniques. With the foundation of PRC and development of economy and technology, bridges with different structures and materials have been gradually built over rivers and valleys.

3.1 ARCH BRIDGE

Arch bridge depends on the arch to be the main load bearing structure. The earliest arch bridge is a stone one transmitting the load of bridge and carrying capacity put on bridge horizontally to piers at the both end of bridge with small units like trapezoid stone. When the small units push and press, they increase intensity of bridge in the meantime. Many ancient bridges are arch bridges not only because it arch formed by arc is steadier than straight girder, but also because arch bridge looks beautiful. The most famous arch bridge is Zhaozhou Bridge. After withstanding thousands of years of wind, rain and earthquake, it is still playing an important role today.

Wushan Yangtse River Bridge, which is honoured as the first bridge at east Chognqing, is an arch bridge with half-through concrete-filled steel tube. The chord is straight steel pipes with major diameter. Elevation web member is composed of vertical and horizontal way of arrangement to improve the angle between web member and chord member. Wanxiang county Yangtze River Bridge, which is the largest concrete arch bridge in the world at present, is 856.12 meters long, 24 meters wide and 147 meters high. The main span is 420 meters. The main arch ring is of composite structure with high strength concrete and steel-tube concrete stiff framework. Chaotianmen Bridge, which is 552 meters long, is an arch bridge with the biggest steel truss. It proposes a composite of rigid and flexible structure. In construction, cantilever construction is achieved through counter weight, cable-stayed fasten and hang system. The techniques of unstressed fold of arches in the mid-span are also adopted.

The construction of Wushan Yangtse River Bridge, Wanxian County Yangtse River Bridge and Chaotianmen Bridge fully indicates that Chongqing has reached a world-class in building concrete arch bridge, steel-tube concrete bridge and steel arch bridge and that the construction of arch bridge in Chongqing has stepped into the international level.

3.2 SUSPENSION BRIDGE

Suspension Bridge is also called hanging bridge. The towers at the both ends of bridge bears the strength of suspension bridge and the suspension cable between two towers hold bridge floor. Suspension bridge is the main form of long-span bridges. Except for Sutong Bridge and The stonecutters bridge in Hong Kong, other bridges with above 1000m span are all suspension bridges. China has the earliest recorded history of suspension bridge. Until today, suspension bridge is still influencing development of hanging bridges in the world.

Zhongxian County Yangtze River Bridge locates in Xiadukou, Zhongzhou Town, Zhongxian County, Chongqing. It is a bridge with the main span of 560 m and the length of 1200 m. Opened to traffic in 2001. The bridge is built into spatial steel tube truss and stiffening girder structure and is characterized by higher stiffness, stiffness of torsion, wind stability and low investment. Besides, the roof falling structure of tunnel anchor and stone anchor is also domestically unprecedented. The stress distribution of surrounding rocks is improved and security increased.

Egongyan Bridge, which located in the downtown of Chongqing city serves as the main channel connecting Chengdu-Chongqing expressway and Chongqing-Guizhou expressway. Built in 2000, the bridge with the 600m main span is 1420 meters long and 35.5 meters wide. It is a two-way bridge with six lanes and the place for light rail is also pre-reserved. Since it is the only continuous stiffening steel box girder suspension bridge.

The Second Wanzhou Yangtze River Bridge, which located in Juyutuo, Wanzhou District, Chongqing city, is 1153.86 meters long and 20.5 meters wide with the main span of 580m. The main cable of suspension bridge is pre-ordered galvanized parallel wire with high stiffness. Stiffening beam is of spatial truss structure of steel tube. The bridge is also characterized by largest tunnel anchorage structure adopting anchorage pre-stressing anchor system whose way of force transmitting is largely improved compared with the previous steel anchor system and therefore, the intensity of high-strength material can be fully exerted.

3.3 CONTINUOUS RIGID FRAME BRIDGE

Continuous rigid frame bridge is a consolidated continuous bridge of pier and girder. It falls into multi-span rigid frame bridge with continuous girder and multi-span continuous rigid frame bridge. Both uses pre-stressed concrete structure. More than two main piers are consolidated by pier and girder. It has the advantage of T-shaped rigid frame bridge.

Continuous Rigid Bridge is one of the main types of bridges with 100m-300m span, it is characterized by simple structure, convenient construction and low initial investment. In Chongqing, continuous rigid bridges have outnumbered other places, so its design, construction and research rank high in China. Among, the most representative one is double line bridge of Shibanpo Changjiang River Bridge designed by Lin Tongyan International Engineering Consulting Co, ltd. Steel box girder section is designed in the 330m main span of this bridge, which is a great innovation. Considering that too much Dead load stress of large-span continuous rigid frame with pre-stressed concrete is bad for span capability, the composite steel-pre-stressed concrete system is adopted, which helps to reduce the dead load and improve the span. The composite steel-pre-stressed concrete system also weakens the negative influence of concrete shrinkage on bridge structure.

3.4 CABLE-STAYED BRIDGE

Cable-stayed Bridge uses one or more main towers and wire rope to support the bridge floor. Among a large number of various cable-stayed bridge, there are some representative ones such as Fuling Yangtze River Bridge, Dafosi Yangtse River Bridge, Lijiatuo Yangtse River Bridge, Masangxi Yangtse RiverBridge, Fengjie Yangtze River Bridge, Jiangjin Guanyinyan Yangtze River Bridge, Zhongxian county Yangtze River Bridge over Shizhong expressway, etc. Fuling Yangtze River Bridge adopts a double longitudinal beam rib-plank structure with pre-stressed concrete. The beam is 2.3 meters high and the plate is 25 cm thick. It is the thinnest main beam of same bridge types in record. Lijiatuo Yangtse River Bridge firstly brought up and successfully adopted flat double main beam structure of pre-stressed concrete at home. The cable-stayed zone of upper pylon is pre-stressed anchor system. The front-point proposes cantilever cradle quick construction techniques. Jiangjin Guanyinyan Yangtze River Bridge, which is a cable-stayed bridge with concrete composite girder, is also the biggest composite girder bridge. Another difficulty lies in the construction of bridge foundation of main pier in deep-water. Fast-flowing water makes the construction even more difficult because work has to be done during the dry season. The design and construction of these cable-stayed bridges broke so many domestic records and also filled many technical blanks. Some of indexes and performance rank first in Asia and even in the world, which indicates that the construction of cable-stayed bridges at Chongqing has reached a world-class level.

4 The development and evolution of bridges at Chongqing from cultural and artistic view

It is the mountains and rivers that decide the soul of Chongqing because bridge is built over the shock of people’s soul. There is deep culture connotation behind the name of “bridge city”.

Chongqing, a city which carries the 3000 years civilization. When it gets dark, the lights on the bridge create such a beautiful arch that it feels like a fairyland to linger on. People also composed a poem to praise Shibanpo Yangtse River Bridge.

Bridge witnesses history because every old bridge brings us into a time tunnel to feel Chongqing civilization. Every bridge is endowed with different spirit and souls for its exquisitely carved stone and delicately designed bridgehead buildings. Place yourself in “city of bridge” to appreciate different views of ancient and modern bridges, see ancient culture, feel vicissitudes of the years, look at the views of times, sing the praise of prosperity of society, pass through ancient and modern times to continue the glory of Chongqing.

5 Application of mechanics in bridge engineering

Before the middle 19th century, the bridge construction uses support to assemble steel girder and to pour concrete girder, making the girder be free from stress in the whole construction process. The cantilever construction of bridge has moved from steel bridge to pre-stressed concrete bridge, which provides a strong construction technique support for the development of pre-stressed concrete cantilever Girder Bridge, continuous girder bridge, continuous rigid frame bridge, arch bridge, cable-stayed bridge and other long-span bridges and starts a new era of development of long-span bridges [12-15].

Construction is growing out of nothing, from natural to artificial, from low level to advanced level. Mechanics development also serves as the foundation to construction. The stability is one of the most important factors of all constructions. Although some building like the Leaning Tower of Pisa and hanging garden which look unstable, but they are firm from mechanics perspective. Now, people care about three basic factors when design bridges, namely, practicability, economization and beauty. Especially, because of complicated construction forms and great population pressure, the rationality of structure must be taken into consideration. While the construction serves its practicability, it also must serve economical applicability.

The mechanic theory in arch bridge is to transfer all or most of bending moment stress caused by load to compressive stress through horizontal thrust. Simply speaking, the longitudinal force is transferred into lateral force through internal force of bridge to work on basis of two sides of bridge, so the bridge must be constructed in areas with solid foundation. The bending moment of strut beam is the largest, followed by cantilever beam, statically determinate multi-span beam, three-hinged rigid frame, composite structure, truss and three-hinged arch with reasonable arch axis have zero bending moment) [16-18].

For example, when the superstructures (segmental beams, arch rib) need to cross deep water, valleys and navigable rivers or when bridge must be built during flood season, bridges are usually constructed without support hoisting segment by segment with cable rope. When hoist place and assemble the prefabricated parts, the stress state of these parts is different from the working condition of finished bridge. The location and number of suspension point of parts should be assured and calculated before construction. Segment of beam and arch rib usually uses two-point suspension point. When segment or curvature of part is large, it is better to use four-point suspension point. The best location of suspension point should be based on the stability and reasonable load carrying capability when hoisting these parts although the influence of other secondary factors should be taken into consideration. The selection of the most suitable suspension point in hoisting of cable rope should be based on the maxim tensile stress as control objectives to identify the four-suspension point of section. As for indeterminate problem of variable cross-section part of two-point suspension and four-point suspension, optimization and iteration methods and summing trial methods [19] can be used to calculate the change rule of suspension point and practical results.

FIGURE 12 Hoisting of Rigid Frame Arch Bridge

If section parts are similar, then uses straight girder to calculate. When the upper and lower allocation of the section of part is equal and when two-point suspension is used, the stress feature of part is like that of double overhanging and simply supported beam. Suspension points should be symmetrically arranged. The controlling object is the absolute value of maximum negative bending moment M1 equals the absolute value of maximum positive bending moment M2 at mid-span, which leads to x=0.207L (L is the length of arch rib part). Taking the factors such as the eccentricity tensile pressure produced by cable, numbers of reinforcement of upper and lower reason, the connector of the tip and the location of gravity of bending arch rib in to consideration, the actual location of suspension point is located 0.22L from the top of arch rib. (L is the length of arch rib part).

When the bridge span is long and shipping ton of hoisting equipment permits, the rib can be prefabricated according to the longer segment (especially the arch part) to avoid air operation. When the curvature of arch is large, four point hoisting and deflecting pulley is also applied. Stress bearing of four-point hoisting of parts belongs to statically indeterminate problem [21-23] and it can be analysed with statically indeterminate girder after using symmetrical semi structure. Choose the basic system as showed in figure 13, the unnecessary unknown force X1 is the positive bending moment M1 in the middle of component. The force method equation is δ11X1+Δ1P =0. Suppose distance between outside suspension point and rod end is X, for the convenience of construction, usually the distance between external suspension point and internal suspension point is 0.2L (when it is less than 0.27L, it bending moment of span is small). Using graphic multiplication method to calculate key coefficient δ11 and free term Δ1P, it can be known that:

$$M_1 = -\frac{\Delta_{1P}}{\delta_{11}} = (\frac{43}{6000} - \frac{13x}{200} + \frac{x^2}{5} - \frac{x^3}{6}) / (\frac{11}{30} - x) \cdot \quad (1)$$

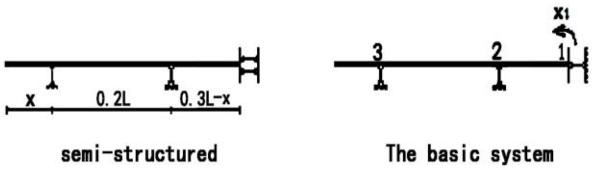

FIGURE 13 Simplification of basic system

Taking

$$|M_1| = |M_2| = |M_3| , \quad (2)$$

as controlling objective, statically indeterminate can remain unknown. Though

$$(0.3L - x)^2 / 4 = x^2 / 2 , \quad (3)$$

we can directly get x = 0.124L.

To adapt to the change of internal force, the solid web section of vault of continuous girder, overhanging girder and trussed arch and rigid frame arch usually uses vertical variable cross-section. The rules of variation of sections are usually straight line or second degree parabola and two-point and four-point suspension are usually used. The identification of suspension point of variable cross-section, even it is two-point suspension, is a statically indeterminate Problem. Taking two-point suspension of variable cross-section part of parabola as an example (graph 14), thickness B=1 and unit weight γ=1 to calculate.

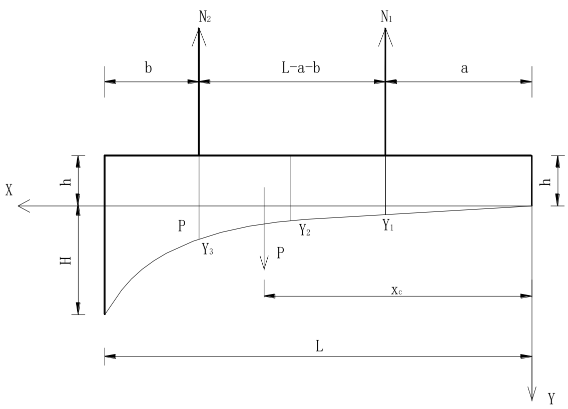

FIGURE 14 Two-point suspension of variable cross-section part

Here, the optimal controlling object is to keep the upper and lower reason of largest tensile stress of section of suspension point and section in the span as small and equal as possible, which is especially important for lightly reinforced concrete part.

Location of the centre of gravity:

$$X_C = \frac{3(2h+H)L}{4(3h+H)} . \quad (4)$$

Controlling bending moment of section:

$$M_1 = \frac{a^2}{12}(6h+y_1), \quad M_3 = \frac{hb^2}{2} + \frac{HL}{12}(4b-L) + \frac{y^2}{12}(L-b)^2, \quad (5)$$

$$M_2 = -\frac{M_1+M_3}{2} + \frac{L_1^2}{96}(12h+y_1+10y_2+y_3) . \quad (6)$$

In which:

$$y_1 = \frac{Ha^2}{L^2}, \quad y_3 = \frac{H(L-b)^2}{L^2}, \quad y_2 = \frac{H(L+a-b)^2}{4L^2}, \quad L_1 = L-a-b . \quad (7)$$

As for lightly reinforced or plain concrete, modulus of bending resistance section is

$$W_i = \frac{(h+y_i)^2}{6}, \quad (i = 1, 2, 3) . \quad (8)$$

Optimal object:

$$\sigma_1 = \sigma_2 = \sigma_3 \quad (9)$$

that is to say

$$\frac{|M_1|}{W_1} = \frac{|M_2|}{W_2} = \frac{|M_3|}{W_3} . \quad (10)$$

Here, the largest bending moment should be replaced with section bending moment to avoid the valuation of bending moment one by one. Error should be less than 2%. For the stability of calculation and easy controlling of preciseness of calculation, after input of constant *L*, *H* and *h*, the non-dimensional method is used to process. *H=0* is uniform section. Try to calculate *a* and *b* value on computer with reasonable step size. Firstly, using starting value of *a* to calculate σ1 within 0～0.5L or even smaller given area and using 0.618 method to iterate one by one to shorten interval. σ2=σ3 is the objective every time you take a value an method of advance and retreat is used to get the *b* value, moreover, ∣σ1-σ3∣ <ε (ε is given preciseness) is used to control iteration. After getting required preciseness of two suspension points with possibly less times of iteration, the vertical component of cable force of two cables can be determined with the location of centre of gravity. As for variable cross-section part, the cable force of two suspension cables cannot be equal.

The reasonable section stress (some sections of suspension point and weak and sensitive sections of part) should be the controlling objective to determine the best suspension point of four-point suspension of variable section parts. Solid web section of vault usually uses four-point suspension. Using summation method to trial gets the result that satisfies the preciseness of construction [20].

Suspension bridge has long span, but it is vulnerable to wind and can even be damaged by strong wind. Wind-resistance is the key problem in the construction of this flexible bridge. Stability can be improved by the careful design in fluid mechanics. From 1818 to the end of 19th century, vibration caused by wind at least destroyed 11 suspension bridges.

After the Second World War, people started to study the destruction of Tacoma Bridge by wind. Some Aeronautical engineers believed that the vibration of Tacoma Bridge is like vibration of wing and they reproduced this wind-induced torsion divergence vibration through wind tunnel testing of bridge models. In the meantime, hydromechanics expert represented by Von Karman believes that different from stream-line wing, blunt-pointed H section of the main girder of Tacoma Bridge has obvious vortex loss, so it should be explained with vortex shedding vibration. In 1950s, the two ideas are controversial until 1963 when American professor R. Scanlan put up separated flow self-excitation flutter theory of blunt body section, the vibration mechanism causing wind destruction of Tacoma Bridge was successfully explained, which also laid the theoretical foundation for bridge flutter. Canadian professor Davenport started a method of analysing bridge buffeting with random vibration theory. This theory became more workable after being revised by Scanlan in 1977. It is safe to say that Scanlan and Davenport laid a good foundation for wind vibration theory of bridge.

Because of the participation of pier, the working condition between continuous rigid bridge and continuous girder bridge is different. As for continuous rigid bridge, positive bending moment in mid-span area caused by live load is smaller than continuous girder bridge with same span. When pier reaches a certain height, the internal force of superstructure of two bridges is nearly the same. By comparing the span between continuous rigid with three spans and continuous girder superstructure with three spans, it is found that the spans of dead and live load at the root of girder are basically the same. When the pier is 40m high, the difference between the dead and live load of mid-span of girder is less than 10%. The span of dead and live load at the root of pier of continuous rigid bridge decreases with the increase of the height of pier, but when the pier is above 40m, the rate of decrease becomes low. The axial tension of dead and live load of inner part of continuous rigid girder decreases with the increased height of pier, but when the pier is above 30 m, the rate of decrease becomes low.

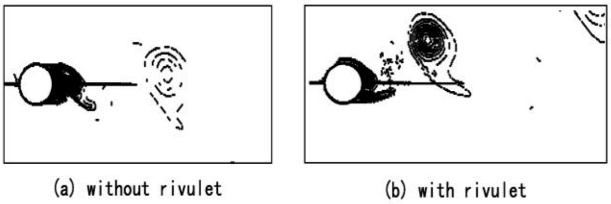

FIGURE 15 Contour line of streaming vorticity

Except for the whole vibration of bridge structure, the cable of cable-stayed bridge also vibrates with the strong wind and heavy rain, which means that the rope of cable-stayed bridge vibrates heavily with the coming of rainstorm and strong wind. This interesting phenomenon was firstly found in 1990s. It can be explained that the rain flows along cable to make a raised waterway called rivulet on the cable, destroying the rounded profile of section of cable. With rainstorm and strong wind, when the raised shape of rivulet suits its position on the cable, a self-induced mechanism is formed, producing self-induced vibration. Professor Ren Wenmin from department of engineering mechanics of Qinghua University used the method of calculating aerodynamic to guide his postgraduates to calculate two-dimension flow field around the section of cable. It is found that the rising of rivulet changes aerodynamic performance of cable section, which on the one hand, leads to the sharp decrease of frequency of alternating falls off in wake zone without rivulet, on the other hand, leads to the trace of fall off of vortex drifts horizontally. The former causes change of resonance wind speed and the later leads the rising of negative damping, increasing amplitude continuously. The following pictures are contour map of streaming vorticity calculated by Qinghua University. 15a is contour map of streaming vorticity without rivulet. 15b is the contour map of streaming vorticity with rivulet. The two pictures show the situation when a vibration period gets started. The raised part above the cable of rounded section is rivulet.

In 21th century, China will build long span bridges, which calls for us to do deeper and further basic and applied researches on identification of aerodynamic parameter of long span bridge, nonlinear wind vibration theory, wind tunnel simulated experiment and data analysis.

6 Conclusions

The development of bridges is summarized from two aspects in this chapter with emphasis on world bridges and Chongqing bridges. Firstly, by a brief introduction and summary of bridge types, theories of bridge design and evolution of bridge construction techniques and the development and evolution of bridges around the world are introduced. Furthermore, the types of bridges, development of theories of bridge design and the breakthrough of bridge construction techniques with time move on are all systemically clarified. Secondly, the process of Chongqing bridge development and evolution is emphasized. On the one hand, when fighting with nature, man remoulded nature and constructed bridge for the convenience of their trips. The progress the man made in the process of remoulding nature is revealed. On the other hand, from the perspective of economy and techniques, this paper clarified the positive role that economical and technical development plays in promoting bridges construction. Finally, the function of mechanics in bridge design is analysed and the development of bridge is experienced from the aspect of culture and art and aesthetics and spirit it brings to people.

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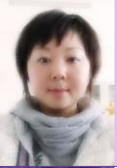

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