The influence of asymmetrical cantilever construction on low pylon cable-stayed bridge of the long span railway

Guo Weiqiang, Chen Quan

School of Civil Engineering, Lanzhou Jiaotong University, China Lanzhou 730070

Keywords: Railway pylon cable-stayed bridge; positive simulation analysis; finite element method

Abstract: At present, most research on the construction of various bridge structure systems in China is still mostly in the construction phase of symmetrical cantilever construction, and the number of literature on the construction of asymmetrical cantilever construction is very limited. Taking a cable-stayed bridge of a long span railway in China as an example, this bridge was simulated and analyzed under the condition of asymmetric cantilever construction with the method of formal simulation and the software of finite element analysis. The measured cable force is collected and compared with the theoretical cable force. The measured cable force is brought into the finite element model of the whole bridge. The analysis shows that the variation of internal force, stress and elevation of the whole bridge under the action of measured cable force meets the requirements.

1. Introduction

Different from the traditional cable-stayed bridge, the main girder of the low pylon cable-stayed bridge is mostly variable section. Due to its small weight and reasonable distribution of internal force, this kind of bridge is mainly in the form of large-span structure. In addition, due to the vertical elastic support of concentrated cable, the bearing capacity of the low pylon cable-stayed bridge has been greatly improved. With the continuous application of high-strength materials in the engineering field and the continuous improvement of construction methods and technologies, the short pylon cable-stayed bridge is developing rapidly at home and abroad [1], and the application field is also expanding.

2. Project Summary

This bridge is a low tower cable stayed bridge with double cable planes on Twin Towers. The main span of the bridge is 120m+208m+120m, which is a continuous girder bridge. The bridge is built on the river, and the main bridge has one or two pier according to the mileage. Along the whole bridge, the cable-stayed cables are arranged in double-sided fan shape. There are 7 pairs of 28 sets of cable-stayed cables, whose horizontal spacing is 8m. The two main towers are both 28m high and are located on the pier 1 and 2 respectively.

3. Establishment of Finite element model

The whole bridge model is established by using Midas/Civil, and the simulation is carried out for the bridge under the condition of asymmetric cantilever pouring in the unbalanced section of side span, and the cable force change under the construction condition is analyzed theoretically. The theoretical cable force of each inclined cable under the construction condition is extracted from the model, so as to make comparative analysis with the actual cable force measured on site. The full bridge finite element model is shown in figure 1 below.

  DOI: 10.25236/icscbd.2018.029

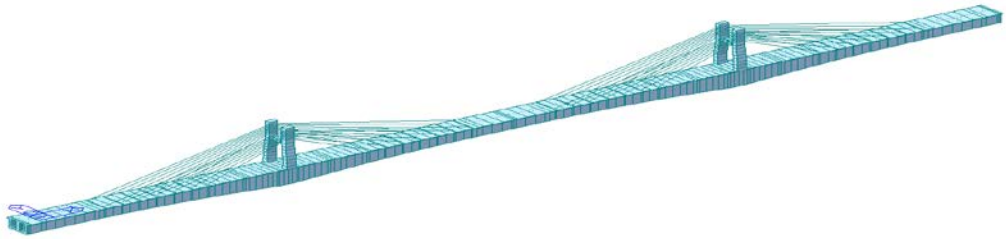

Fig.1 Full bridge finite element model

4. The influence of asymmetric cantilever construction

4.1 Cable force variation of stay cables

The sag effect of stay cable must be considered in the cable force analysis and calculation [2]. It is reasonable to use frequency method to measure the cable force for the cable which is tensioned and is in the state of force.

4.1.1 Sag effect of stay cables

Under the action of wind load and vertical load, the inclined cable vibrates with a certain natural vibration frequency [3]. Figure 2 shows the distribution of the geometric shape of the inclined cable under the influence of vertical effect. The ratio of sag to span is very small($\lambda \ll 1$), and the cable vibrates only in the plane coordinate system shown in figure 2. The displacement of the cable along the direction AB of the straight line section is very small, so the displacement influence in this direction is not taken into account. The deflection in the vertical direction (perpendicular to the direction AB of the straight line section) is considered as $\omega \ll 1$. When the sag ratio is $\lambda \leq 0.2$, the shape of the cable affected by the sag effect can be represented by a parabola. The free vibration equation of the cable in the vertical direction is as follows [4]:

$$EI\frac{\partial^4 \upsilon(x,t)}{\partial x^4} - H\frac{\partial^2 \upsilon(x,t)}{\partial x^2} - h(t)\frac{\partial^2 y}{\partial x^2} + m\frac{\partial^2 \upsilon(x,t)}{\partial t^2} = 0 \quad (1)$$

Formula 1: H indicates the tension of the cable in the direction of AB in Fig. 2. α represents the Angle between the cable and the horizontal direction; m represents the line density of the cable; EI represents the bending stiffness of the cable; h(t) represents the tension increment caused by vibration of cable under load.

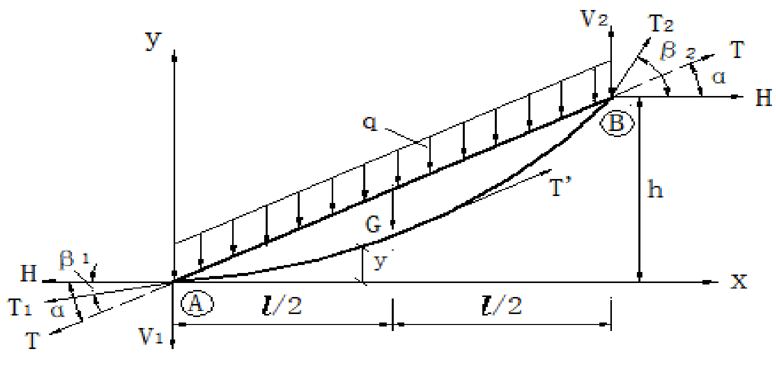

Fig.2 The geometric shape under the sag effect of the inclined cable

According to the above analysis, the change rule of the cable shape along the AB direction perpendicular to the straight line can be expressed as:

$$s = \frac{4f}{l_0^2}x(l_0 - x) \quad (2)$$

Formula 2: f indicates the sag; l_0 represents the radial length of the cable along the direction

AB. It can be obtained by the Irvine formula [5]:

$$\frac{h}{EA}\left(\frac{dw}{dx}\right)^{3}=\frac{\partial u}{\partial x}+\frac{dy}{dx}\frac{\partial \upsilon}{\partial x} \quad (3)$$

Formula 3: dw represents the micro segment along the curve arc of the stay cable; EA represents the tensile stiffness of stay cables.

4.1.2 Calculation and analysis of cable force of cable-stayed cable

(1) Calculation method

This paper mainly USES the frequency method [6] to measure the cable force. In the process of tension completion, the cable will have a natural vibration frequency. The natural vibration frequency is collected by the cable dynamic tester. The equation of formula (1) is taken as the separation variable, and it is assumed that the connection mode of the two anchor segments of the cable is articulated. Therefore, the relationship between cable force and natural vibration frequency can be obtained as follows:

$$F=\frac{4\delta L^{2}k^{2}}{n^{2}}-\frac{n^{2}\pi^{2}}{L^{2}}EI \quad (4)$$

Formula 4: L shows that the distance between anchorage points of stay cables; $\delta$the mass of stay cables per meter; n the natural vibration order of stay cables are expressed.

(2) Modification of cable length

When calculating the length of the cable, it is usually corrected, so the ratio coefficient of the cable should be considered G. The formula is as follows:

$$G=\frac{4L^{2}}{P}\delta \quad (5)$$

Formula 5: P represents the coordination coefficient.

The following formula can be used to correct the cable length:

$$L=L_{0}-R(W_{1}+W_{2}) \quad (6)$$

Formula 6: R represents the correction and adjustment coefficient of the cable; W_1、W_2 denotes the rigidity length of two anchoring ends of the stay cable.

4.1.3 Comparative analysis of theoretical cable force and measured cable force

Based on the above theoretical cable force extracted from the model and the relationship between the theoretical cable force and the cable frequency, the theoretical base frequency is calculated. Then, the field natural vibration frequency is collected with the theoretical base frequency as the reference standard, and the measured frequency is converted into the measured cable force according to the above formula (4). The pier 1 and 2 of the whole bridge have small mileage side and large mileage side respectively. As the whole bridge is a symmetrical structure system, only the cable force value of 1/2 side of the whole bridge is compared and analyzed. The measured cable force of C1 of the large mileage side is 5.06% larger than the theoretical cable force, exceeding 5%[7]. It can be seen that the force exerted on the inclined cable after the asymmetric cantilever pouring in the unbalanced section of side span is relatively uniform, and the deviation between theory and practice is generally small. The comparison diagram of the two is shown in figure 3 below.

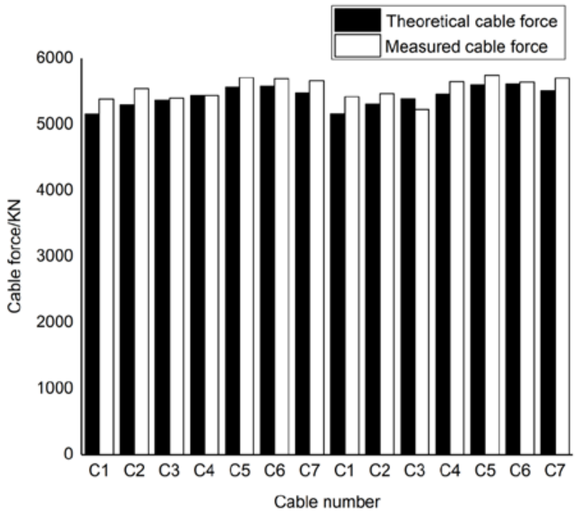

Fig. 3 Theoretical cable force and measured cable force on 1/2 side

4.2 Influence of cable force variation on internal force and line shape

According to the force exerted on the cable-stayed bridge of the short tower, the variation of cable force is crucial to the control of internal force and line shape [8]. The measured cable force values are brought into the finite element model of this bridge for the formal simulation analysis [9-10], and the stress, bending moment and elevation changes of the upper and lower flange of the main beam are obtained as shown in Fig. 4, Fig. 5 and Fig. 6.

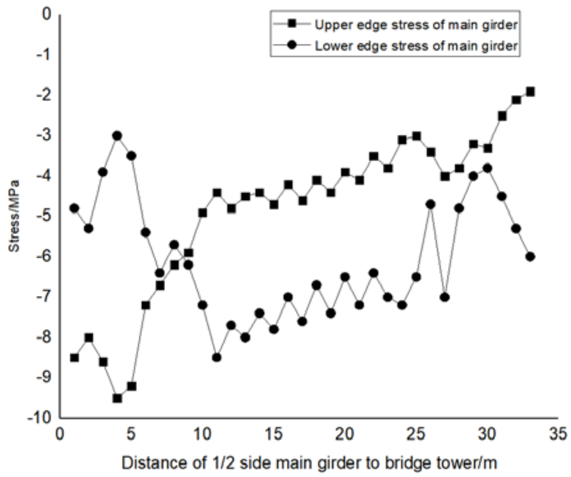

Fig. 4 Upper and lower edge stress of 1/2 side main girder

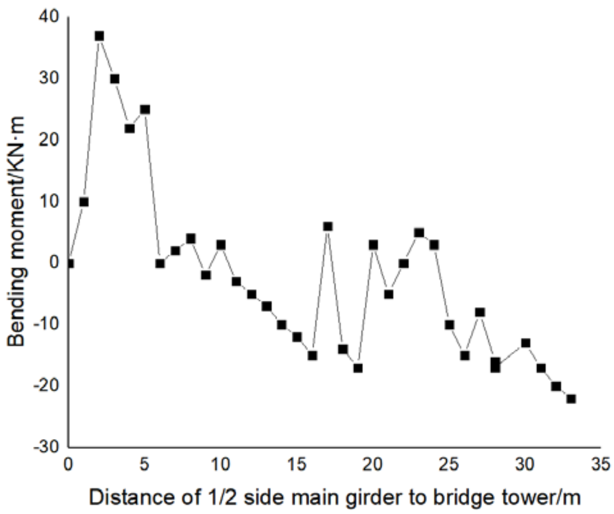

Fig. 5 Bending moment of 1/2 side main beam

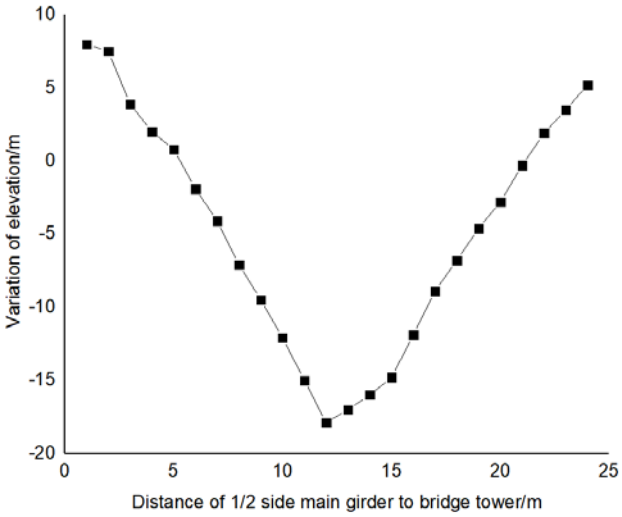

Fig. 6 Elevation variation of 1/2 side girders

It can be seen from the above figure 4 that the stress of 1/2 side main girder is compressive stress. As the stressed member of prestressed concrete, the main girder of this bridge must meet the compressive strength designed by it. From the stress change of 1/2 side main girder, the stress of the structure meets the requirement of compressive stress. It can be seen from Fig. 5 that the change rule of bending moment value of 1/2 side main girder first appears positive bending moment, and then gradually transitions from positive bending moment to negative bending moment. After the casting of asymmetrical cantilever in the unbalanced section of side span, the upper tension tends to occur on the cross section of side span and middle span main girder, but the overall structure is still in the state of compression, which can effectively avoid the failure caused by excessive tensile stress on the structure surface. Therefore, the overall internal force distribution of the structure is reasonable. As can be seen from the change of the bid height in Fig. 6, the side of the main girder has deflection at the side, while the side near the middle span has deflection at the side.

5. Conclusion

The above analysis is a calculation and analysis process combining theory with practice. The analysis of cable force takes into account the influence of vertical effect. Through the measured natural vibration frequency of the cable, the actual cable force is calculated by using the relationship between cable frequency and cable force. As the cable-stayed bridge of short tower is a kind of high-order ultra-static structure, it plays an important role in the construction and completion of the bridge, and the cable force can be adjusted to make the internal force, stress and line shape of the structure reach a reasonable state. Therefore, this paper also analyzes the variation trend of stress, bending moment and elevation of 1/2 side of the symmetrical structure under the change of cable force. The results show that the main girders are under compression, which meets the compressive stress requirements of the structure, and the structure has sufficient compressive stress reserve.

From the bending moment distribution, main girder is the alternation of the positive and negative bending moment, consistent with the actual stress, and the variation in the range of feasible region. From the point of elevation variation, when under the unbalanced cross section of the casting after edge is scratched, this is because the concrete casting after the girder due to gravity tends to sink, when later through tensioning beam body can be lifted, the positive and negative camber beforehand offset each other, to ensure the bridge line smooth. From the above analysis results, it can be seen that the influence of the asymmetric cantilever construction on the internal force, stress and line shape of the structure is controllable. Therefore, in terms of the structure system selected in this paper, the safety and reliability of the structure can be guaranteed during the construction stage of the asymmetric cantilever.

References

[1] Zhan Jian-hui, Zhang Ming. Prestressed concrete partial cable stayed bridge [M].

[2] Li Yan-zhi translation. Design and construction of cable-stayed bridge [M]. Beijing: China Construction Industry Press, 1980.

[3] Irvine H M,Caughey T K.The linear theory of free vibration of a suspended cable[J].Proc Royal Soc London,England,Senses A,1974,341-348.

[4] Guo Liang-you.Vibration characteristics of rope and cable and cable force measurement of stay cables [J]. bridge construction, 1995 (1).

[5] Zheng Li.construction control of short tower cable-stayed bridge [J].

[6] Guo Liang-you, Lin Yi-ning, Li Wen-bo, et al. Measurement of cable tension, temperature and stress in the Second Yangtze River Bridge in Wuhan [J]. Bridge construction, 1995 (3).

[7] Wang Wei-feng, Han Da-jian. Cable tension test and parameter identification of cable-stayed bridge [J]. Journal of South China University of Technology (NATURAL SCIENCE EDITION), 2001, (1).

[8] MICHEL,Virlogeux.Recent evolution of cablestayed bridges[J]. Engineeering Structures, 1999, 21(8):737-755.

[9] Xiang Hai-fan, Yao Ling-sen. Theory of advanced bridge structure [M]. Beijing: People's Communications Press.2010:282 - 288.

[10] Huang Qiao, Wu Hong-lin, Li Zhi-bo. Determination of cable forces in cable-stayed bridges bypositive calculation method [J]. Journal of Harbin Institute of Technology, 2004, 36 (12): 1702-170.