Calculation and Analysis of Box Girder Temperature Effect of Large Cantilever Bridge under the Solar Radiation

Wang Cheng¹, Liu Wenchao¹,²*, Chen Zheng³

¹Technology Research and Development Center, CCCC Fourth Highway Engineering CO., LTD., Beijing, 100022, China
²Office of Postdoctoral Research, Beijing University of Technology, Beijing, 100124, China
³Key Laboratory of Urban Security and Disaster Engineering, Beijing University of Technology, Beijing, 100124, China

*Corresponding author’s e-mail: liwenchaoann@foxmail.com

Abstract. This paper analyzes the influence of solar radiation on the prestressed concrete wide box girder with a large cantilever. The experimental research is carried out by arranging the embedded deformation monitoring sensor, and the actual temperature deformation curve of the large cantilever box girder subjected to solar radiation is obtained. Besides, the deformation calculation model of box girder under the influence of solar radiation is established by ANSYS finite element software, so as to obtain the deformation distribution of large cantilever prestressed concrete under solar radiation. Calculation results are fitting well in with the actual tested results, with an average error of 7.97%. As the boundary conditions are quite ideal, the tested results tend to be larger. Relative studies can provide some guidance and suggestions for the deformation control and design of this type of bridge.

1. Introduction

Buildings such as large bridges will continue to rise in temperature under sunlight, resulting in a temperature effect on the overall structure, which is deformation and cracking of the structure [1-3]. The construction quality problems should be avoided as much as possible during the construction of the project. Therefore, the calculation and analysis of the temperature effects of the relevant structures under the action of solar radiation is particularly salient. According to the literature [4-7], the box girder in the large cantilever bridge structure is particularly affected by the temperature effect and is related to the geographic latitude, atmospheric transparency, sunlight and structural section size. In the current materials about specification, the calculation method of the temperature difference of the box girder is based on the previous engineering experience and combined with relevant domestic and foreign data, while the research on the experimental monitoring and theoretical calculation of the box girder temperature effect of the large cantilever is relatively rare. Targeting at the temperature deformation of the box girder, this paper analyzes its distribution law under the effect of solar radiation with the test monitoring and finite element analysis, which provides guidance for actual engineering construction. In this way, unfavorable consequences are impaired by interfering before.
2. Project overview
The Hengqin Second Bridge is located in the southwest of Zhuhai City. Its south approach bridge is 5087.02m long and the standard beam width is 33.5 meters. It has 6 two-way lanes, all of which are equipped with cast-in-place box girders on the large cantilever. The beam height at the centerline of the route is 250cm, and the cantilever on both sides is 717.4cm. The top of the box girder is 25cm thick, the bottom plate is 17.50m wide and 25cm thick. The end of the beam is provided with a small longitudinal girder in the longitudinal direction, and it is 45 cm high and 80 cm wide. The curved plate at the lower edge of the beam adopts an elliptical curve, and the curved lines of the fully connected curved plate are uniform. The plate thickness is the same as the lower flange of the provocation, which is 20cm. The bridge structure of the project is relatively complicated, so the requirements for overall bridge deformation control are high during construction.

3. Test monitoring and calculation analysis of temperature deformation

3.1. Test monitoring
In order to reflect the effect of the temperature, the deformation of the box girder is observed. Under the premise of meeting the relevant requirements, by reasonably optimizing the deformation observation points, the A-A section with the same observation section of the box girder deformation and the temperature test section is finally determined. The deflection observation points are shown in Figure 1. There are 5 deformation observation points, and the test time and temperature measurements are performed simultaneously. The deflection test uses the imported Lycra leveling rod and a 5-meter box staff with monitoring accuracy of 1 mm.

Figure 1 Schematic diagram of the deflection measuring point of A-A section

3.2. Finite element calculation model
The finite element analysis model of the large cantilever prestressed concrete continuous wide box girder 4×42m of the south approach bridge is established by the finite element analysis software ANSYS. The SOLID70 thermal analysis unit can calculate the deformation value of corresponding positions. Specific parameters in the model are shown in 3.3.1.

3.3. Finite element calculation and analysis

3.3.1. Analysis of deflection calculation
Figure 2 shows the deflection distribution at 2 PM when the measured deflection is maximum. It can be seen that the top plate has the camber near the mid-span of the first span and the fourth span, with a slight down deflection between the third and fourth spans. On both sides of the top plate, there is the down deflection, and the height difference from the middle to the top plate reaches 1.7 cm. The part where the down deflection is largest is in the mid-span of the second span with the maximum value of 1.1 cm.

Figure 3 is a deflection distribution at 6 AM. Comparing the deflection distribution at 2 PM, it can be seen that the deflection at both moments manifests itself in sagging on both sides of the middle convex. The difference in deflection distribution at 6 AM is small, and the overall deflection is also far below that at 2 PM with the maximum deflection of 0.4 mm.
The specific analysis of the first span deflection is taken as an example. From the deflection distribution of the section in Figure 4(a), it can be seen that when the box girder is near the central axis of the bridge, the deflection is small, and the deflection towards the sides increases. Figure 4(b) illustrates that a large range of camber occurs near the mid-span of the first span, with a maximum height of 4 mm. According to the analysis of Figure 4(c), under the effect of solar radiation, the box girder is deformed to be sagging on both sides of the middle convex.

(a) Top surface of the first span at 2 PM  
(b) Cross-section of the first span at 2 PM
Comparing the deflection distribution at 12 noon, 4 PM and 6 PM which are before and after 2 PM (Figure 5 to Figure 7), the following conclusions are drawn: (1) The calculated deflection at 4 PM is larger than that at 2 PM, indicating that the temperature effect exists a certain lag. The maximum value occurs after the temperature reaches the maximum value for a period of time; (2) The deflection distribution is similar at 12 noon, 2 PM, 4 PM, and 6 PM, and both show a sagging on both sides of the middle convex.
3.3.2. **Comparison of measured values of deflection and calculation results**

The error under temperature between the calculation results of concrete box girder deformation and the measured results is further analyzed, so as to verify the accuracy of the FEM finite element model. The changes with the calculated and measured values of the deflection of the 5# measuring point on the right side of the mid-span in the first span are given, as shown in Figure 8.

As is shown in the results, actually tested deflection is fitting well in with calculated deflection, with an average low error of 7.97%. It indicates that the finite element model can better simulate actual circumstances on site. It can be learned from figure 9 that different section shares different maximum deflection value. The maximum deflection of the mid-span in the right second span is 11.6mm. Also, the deflection trend of different section is basically the same, that is, the deformation is larger at 8-14h, and the deformation is smaller at other times. The overall deflection is relatively small, suggesting that the deformation caused by the temperature under the solar radiation has little effect on the deformation of the box girder structure.
4. Conclusion
In summary, under the influence of temperature, the box girder will produce an uneven vertical displacement of lateral and longitudinal distribution, and the difference of deflection is close to 2cm, which should cause design and construction attention and be given full consideration.

(1) When the box girder is near the central axis of the bridge, the deflection is small, and the deflection towards the sides increases. A large range of camber occurs near the mid-span of the first span, with a maximum height of 4 mm.

(2) There is a certain hysteresis effect on the deformation of the whole structure under high temperature, and the deformation value is relatively small, which has little effect on the overall structure safety.

(3) Using the ANSYS finite element software to establish an analytical model is conducive to better simulation of the actual site. The calculation results are in good agreement with the measured results.

Acknowledgments
The authors would like to acknowledge the financial support from the Key Research and Development Plan of Beijing Municipal Science and Technology Commission (Grant NO. Z161100001216012), China Postdoctoral Science Foundation (Grant NO. 71001015201705) and the Beijing Postdoctoral Science Foundation (Grant NO. Q6001015201702).

References
[1] Shih Toh Chang. Prestress Influence on Shear-Lag Effect in Continuous Box-Girder Bridge[J]. Journal of Structural Engineering, 1992, 118(11):3113-3121.
[2] Mirambell, Enrique, Aguado, Antonio. Temperature and Stress Distributions in Concrete Box Girder Bridges[J]. Journal of Structural Engineering, 116(9):2388-2409.
[3] L.M.C. Simões, J.H.J.O. Negrao. Optimization of cable-stayed bridges with box-girder decks[M]. Elsevier Science Ltd. 1997.
[4] Xie, Jun, Wang, Guo-liang, Zheng, Xiao-Hua. Review of Study of Long-term Deflection for Long Span Prestressed Concrete Box-girder Bridge[J]. Journal of Highway & Transportation Research & Development, 2(2):47-51.
[5] Y. L. Mo, C. -H. Jeng, H. Krawinkler. Experimental and analytical studies of innovative prestressed concrete box-girder bridges[J]. Materials & Structures, 2003, 36(2):99-107.
[6] A. G. Razaqpur, Mostafa Nofal, M. S. Mirza. Nonlinear analysis of prestressed concrete box girder bridges under flexure[J]. Canadian Journal of Civil Engineering, 2011, 16(6):845-853.
[7] Paramita Mondal, John T. DeWolf. Development of Computer-Based System for the Temperature Monitoring of a Post-Tensioned Segmental Concrete Box-Girder Bridge[J]. Computer-Aided Civil and Infrastructure Engineering, 2007, 22(1):65-77.