Academic Journal of Architecture and Geotechnical Engineering
ISSN 2663-1563 Vol. 5, Issue 1: 1-7, DOI: 10.25236/AJAGE.2023.050101

Construction monitoring of a long-span prestressed concrete continuous box girder bridge with variable sections

Dong Xu, Liu Dehua, Meng Chunyu, Wang Peihe, Wang Puxu

School of Transportation and Civil Engineering, Shandong Jiaotong University, Ji'nan, 250357, China

Abstract: *The structural behaviors in each construction stage were monitored and analyzed against the background of a long-span prestressed concrete continuous box girder bridge with spans of 55+100+55 m. At first, the formwork erection elevation and pre-camber of the bridge in each stage, as well as stress values of key cross-sections were determined by simulating the whole construction process using the finite element software. Then, the design parameters were identified and the model was corrected by field data collection and considering various influencing factors, so as to ensure effectiveness of the model. Finally, the formwork erection elevation was adjusted according to the stress and altitude in each construction stage, followed by closure of the bridge. According to field monitoring and adjustment, the measured alignment and stress of the bridge conform to the design and the error meets the requirements of specification, indicating a favorable monitoring effect. The research can provide reference for construction of similar bridges.*

Keywords: *long-span; prestressed concrete; continuous box girder bridge; cantilever-casting; construction monitoring*

1. Introduction

Prestressed concrete continuous box girder bridges are characterized by advantages including high spanning capacity, reasonable stress, convenient construction, smooth running of vehicles, and low maintenance cost, so they have been widely used and become one of the main types of long-span bridges. At present, long-span prestressed concrete continuous box girder bridges are mainly constructed using cantilever-casting method with hanging baskets. The construction process is complex, and the processes of various segments of the main girder in the upper structure include formwork erection, steel bar binding, concrete pouring, prestress application, and forward movement of hanging baskets. These processes are repeated until the bridge is closed and finished. Adverse factors such as the temperature effect and measurement error in the construction process, which may incur construction errors. These errors have interference on the completion of bridges to different extents and may cause problems including difficulty in closure, and unconformity of the alignment and internal force of finished bridges to the design requirements. Because finished segments during cantilever-casting construction cannot be adjusted, the construction process should be effectively monitored and controlled in a bid to ensure that the alignment and internal force of finished bridges constructed through cantilever-casting comply with the design requirements. In the engineering background of a long-span prestressed concrete continuous box girder bridge, the whole monitoring process and key technical points of cantilever-casting construction were expounded to provide reference for similar monitoring engineering[1].

2. Project overview

The upper structure of Weihe super-large bridge (Changyi City, Shandong Province, China) is a prestressed concrete continuous girder with variable sections and spans of 55+100+55 m, and the box girders were fabricated using C50 concrete. In the lower structure, the ribbed plate-type abutments, column piers, and pile foundation are separately used as the bridge abutments, piers, and pier abutments. The single breadth of the box girders is 16.5 m and the structure of single-box single-chamber straight webs is used, with the width of bottom slabs of 8 m. The cantilevers in both flanges are 4.25 m long. The heights of box girders at the root and the mid-span are 6.25 and 2.5 m, respectively, which vary as the second-order parabola. The top slab of box girders is 30 cm thick; the thickness of bottom slabs of box girders changes from 32 to 75 cm from the mid-span to the root in a manner of the second-order parabola. The webs of box girders have three thicknesses: 100 cm thick from the 1st to 4th segments, variable thickness in the 5th segment, 85 cm thick from the 6th to 9th segments, variable thickness in the 10th segment, 55 cm thick from the 11th to 13th segments, and 55 ~ 95 cm thick in cast-in-place segments of side spans. The three-way prestressing system is adopted to the box girders, namely, along the longitudinal (tendons for top slabs, bottom slabs, and webs, as well as closure tendons), transverse (transverse tendons for top slabs and pier top beams), and vertical (vertical prestressed thick steel bars in webs) directions of box girders. The design load is Class I Load of Chinese highways[2-3]. The coefficient for importance of a structure is 1.1 and the design reference period is 100 years, as shown in Figure 1 and Figure 2.

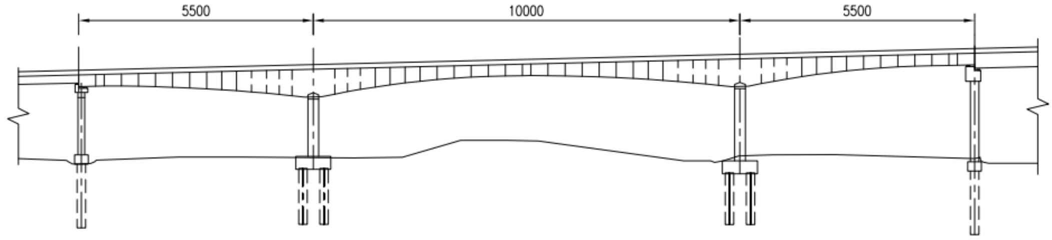
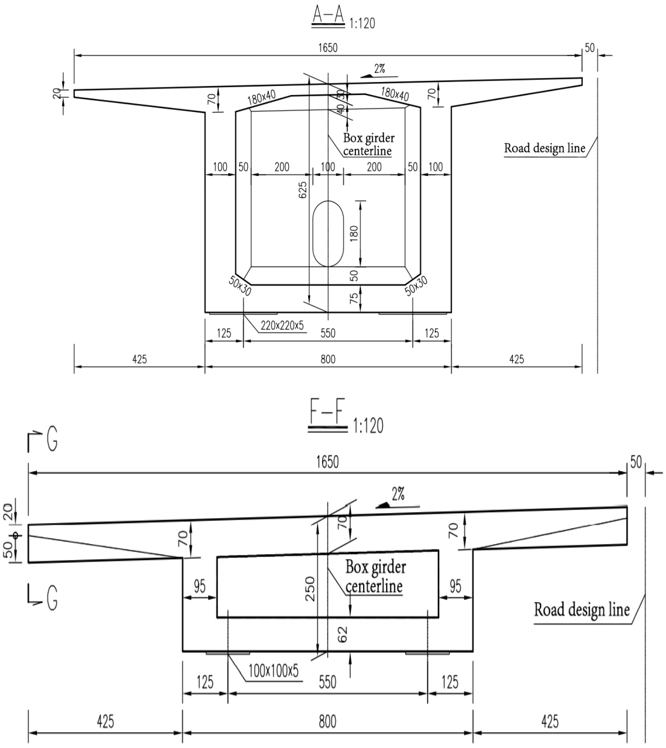


Figure 1: Plat elevation of the bridge (cm)



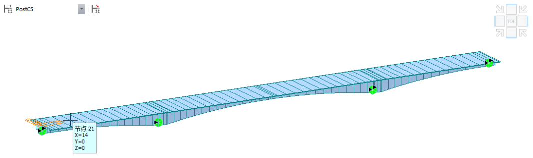
(a) Standard cross-section at the central bearing point *(b) Standard cross-section at the end bearing point*

Figure 2: Standard cross-sections of the box girders (cm)

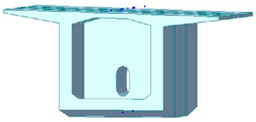
3. Structural calcualtion and analysis

3.1. Finite element modeling

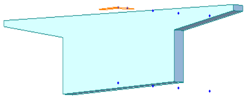
Midas Civil was used as the calcualtion program for solid finite element modeling of the structure. In this way, the main girder structure of the bridge was established. All computing elements were spatial beam elements. The whole bridge contained 87 nodes and 70 elements. The calculation considered the structural dead load, phased construction process, temperature change, construction load, system transformation, and secondary dead load and live load effects. In addition, the structural deformation, internal force, and stress distribution were computed following the bridge construction process in construction organization design, to comprehensively re-check the design. The pre-camber was also calculated. The structural calculation model is displayed in Fig. 3.



(a) Finite element model of the whole bridge



(b) Model of 0# segment



(c) Model of the end of side span

Figure 3: Models of the prestressed concrete continuous box girder bridge

3.2. Determination of pre-camber

Calculation results of the pre-camber include pre-cambers in the construction stage and operation stage, as well as additional pre-camber. Pre-camber in the construction stage is the inverted camber of displacement after completion of the bridge (finishing the bridge deck pavement) obtained using the forward-calculation method based on the theoretical calculation model and determined calculation parameters, combining with construction conditions. Pre-camber in the operation stage is the sum of the inverted camber of displacement generated due to concrete shrinkage and creep for 10 years of operation and the inverted camber of half of the maximum downward displacement under live and dead loads of vehicles. Pre-camber is identical to the sum of pre-camber in the construction stage, pre-camber in the operation stage, and pre-camber under the live load, and it is the formwork erection elevation of top of the girder at each node of the bridge obtained according to the above analysis and calculation results. Software MIDAS2019 of Beijing Midas Information Technology Co., Ltd. was adopted for modeling and analysis. Pre-cambers in the operation and construction stages are illustrated in Figs. 4 and 5, respectively. Pre-camber in the construction stage is adjusted according to the construction conditions[4-5].

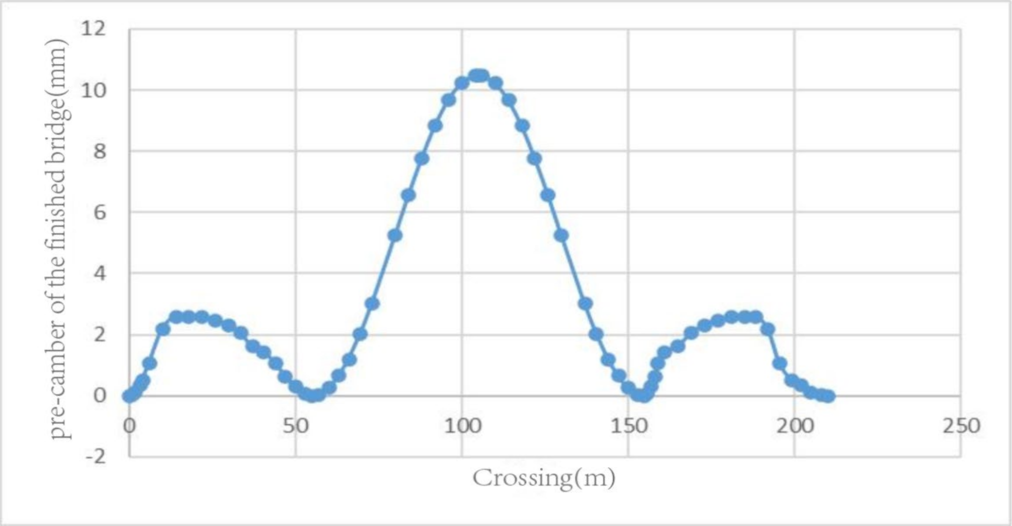


Figure 4: Calculated pre-camber in the operation stage (mm)

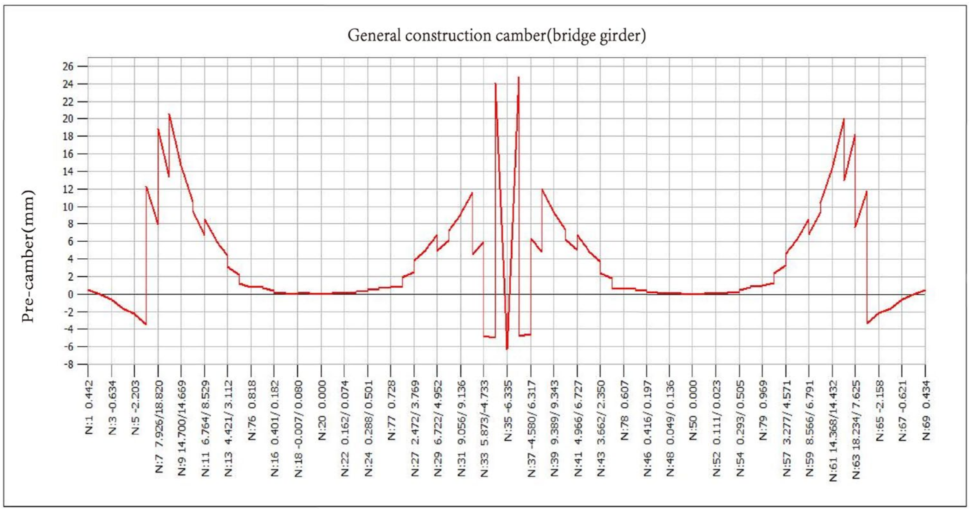


Figure 5: Pre-camber in the construction stage (mm)

4. Construction monitoring

4.1. Deformation monitoring of the girder

4.1.1. Test contents

Deformation monitoring includes of horizontal alignment monitoring and the vertical control survey of box girders as well as monitoring of main pier settlement.

Alignment monitoring is generally conducted through geometric levelling. After measuring absolute altitudes of control benchmarks in each constructed segment, the altitudes of girder bottom of corresponding segments can be calculated according to the height difference between various segments and the girder bottom measured upon completion. To eliminate irregular changes in the girder due to the sunshine temperature difference, the alignment should be measured in time periods of little temperature changes and stable temperature, and the measurement should last as short as possible.

4.1.2. Test locations

Locations of measuring points are displayed in Fig. 6. Six measuring points were set on the cross-section of each box-girder node. Three measuring points were arranged symmetrically on the top slab, in which two were on the flanges and the one in the middle also serves as the monitoring point for surface alignment. The three-stage deflection observation method was adopted for deflection observation. In the first stage, the cast-in-place segments were measured after moving hanging baskets; in the second stage, the cast-in-place segments were measured before applying the prestress; in the third stage, the cast-in-place segments and poured segments were measured after applying the prestress. Measurement of the poured segments mainly aimed to analyze the displacement.

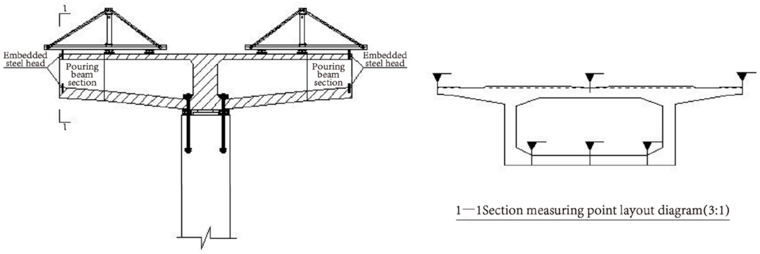


Figure 6: Layout of measuring points for displacement of the main girder

4.2. Stress monitoring of the main girder

4.2.1. Layout of monitoring cross-sections and measuring points

Measuring points for stress of the main girder were arranged as follows: the representative cross-sections of the main girder included the cross-sections in the middle of each span, quartile cross-section of the main span, and cross-sections at abutments. Two most unfavorable locations, namely, the root of box girders and the closure segment were separately selected, as shown in the figure. Four measuring points were set on each cross-section, and their layout was optimized according to stress characteristics of the structure. Stress was monitored segment by segment from 0# segment of the cantilever box girder until the finished stage. Measurement in each stage should provide corresponding working state of the bridge, so as to ensure safe construction of the bridge. Layout of measuring points on the cross-section of the box girder is shown in Fig. 7.

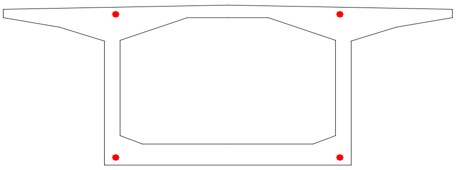


Figure 7: Layout of measuring points for stress on the control cross-section of the box girder

4.2.2. Test instruments and conditions

Considering that instruments should adapt to observation during long-term construction and ensure enough accuracy, long-term vibrating-wire strain gauges for concrete with high stability and accuracy, as well as equipped vibrating-wire readouts were used to test the stress.

The test conditions for strain of the main girder are described as follows:

① Stress measurement of the main girder following the construction sequence of various segments, with three conditions considered for each segment (after installing hanging baskets, after pouring concrete, and after tensioning prestressed tendons); ② before and after incremental launching in the middle span; ③ after finishing closure; ④ after bridge deck pavement and construction of ancillary facilities.

5. Monitoring results

5.1. Monitoring results of deflection

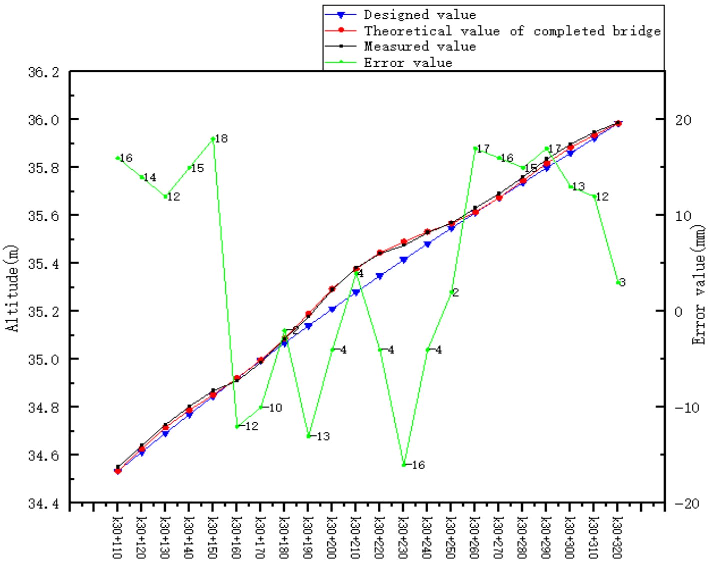


Figure 8: Line chart after phase-2 bridge deck pavement

The line chart after bridge deck pavement is shown in Fig. 8 (only data about the left half of the main girder at 15# pier are shown due to length limitation). Data show that the difference between measured and theoretical altitudes of the main girder is generally in the range of -0.008 ~ 0.007 m. The maximum pre-camber of the completed bridge is about 18 mm, and the difference at measuing points of the main girder is always within the allowable deviation of 20 mm, which meets the control requirements for the alignment of the bridge[6-7].

5.2. Stress monitoring results

Stress monitoring data in the construction process are displayed in Figs. 9 and 10 (only stress on the cross-section at the root of 0# segment in the side span in the left half of 15# pier is provided due to length limitation). Data reveal that the whole cross-section of the segmental box girder is compressed, with the measured maximum compressive stress of 0.64 and 0.55 MPa on the top and bottom slabs, respectively. This indicates that the structure is safe and controllable in the construction process, and the deviation between measured and theoretical values is basically controlled within 20%, satisfying control requirements of construction.

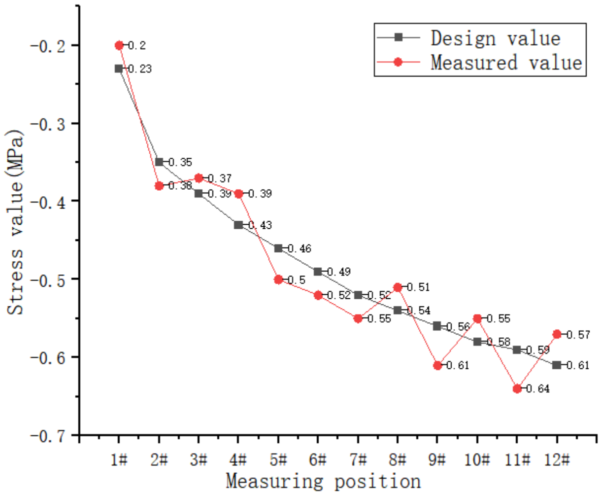


Figure 9: Stress on the top slab on the cross-section at the root of 0# segment

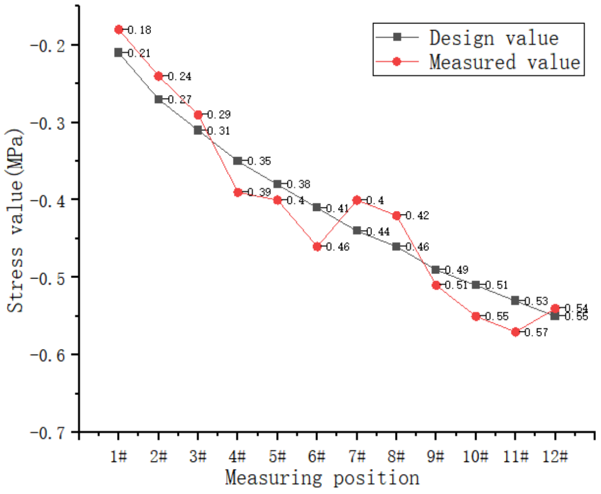


Figure 10: Stress on the bottom slab on the cross-section at the root of 0# segment

6. Conclusions

Finite element modeling and simulation were carried out on the whole cantilever-casting construction process of the long-span prestressed concrete continuous box girder bridge and the reasonable pre-camber was set. The deformation and stress of the main girder in the cantilever-casting construction process were monitored. The deviation caused by important parameters in the construction process was identified and fed back timely and then corrected. The actual finished bridge indicates that the control theories and measures used are effective, and they guarantee that the final alignment and structural stress state meet requirements of the design and specification.

References

[1] Chen Xu. Construction Monitoring Analysis of Long span Prestressed Concrete Continuous Beam

Bridge [J]. Fujian Transportation Science and Technology, 2020 (03): 85-89

[2] Lai Canglin. Monitoring of cantilever casting construction of long-span prestressed concrete continuous box girder bridge [J]. Fujian Construction Science and Technology, 2018 (01): 53-55+86

[3] Wang Xiaokui, Wang Xingguo, Pan Deng. Linear monitoring analysis of construction process of prestressed concrete continuous box girder bridge [J]. Journal of Water Resources and Building Engineering, 2017,15 (06): 76-80

[4] Ding Yandong. Linear Monitoring of Prestressed Concrete Continuous Box Girder Bridge Construction [J]. Journal of Jilin University of Education, 2016, 32 (01): 184-186.

[5] Chen Haidong. Analysis on Construction Monitoring of Long span Prestressed Concrete Continuous Beam Bridge [J]. Science and Technology Outlook, 2015, 25 (22): 22-23

[6] Yao Jianpeng, Liang Mingsheng, Chen Zhongcheng. Cantilever construction monitoring of prestressed concrete continuous box girder bridge [J]. Highway, 2012 (02): 105-108

[7] Hu Qizhi, Zhuang Xinshan, Li Lingyu. Construction Monitoring of Prestressed Concrete Continuous Box Girder Bridge [J]. Northern Communications, 2010 (11): 37-40.