Academic Journal of Architecture and Geotechnical Engineering
ISSN 2663-1563 Vol. 4, Issue 3: 31-36, DOI: 10.25236/AJAGE.2022.040305

Research of construction monitoring technology of large-span variable cross-section prestressed concrete continuous box-girder bridge

Liu Dehua, Dong Xu[*], Gao Kaiyue, Han Qingao, Liu Siying

School of Transportation and Civil Engineering, Shandong Jiaotong University, Jinan, Shandong, 250357, China
[*]Corresponding author

Abstract: *With the advancing development of structural performance and construction techniques, continuous concrete box girder bridges have been widely used due to their advantages including their broad applications, good appearance, and reliable structural safety. However, as the bridge span and its construction demands are increasing, the bridge construction process tends to be more complex. Especially, the construction methods and bridge installation sequences of cantilever bridges not only exert structural internal force on the bridge construction process but also affect the internal force and line shape of the bridge structure of finally constructed bridges. Hence, it is essential to realize bridge construction control. Only in the presence of the excellent construction control performance, can the structural safety in the bridge construction process can be ensured while meeting the designed requirements of bridge line shapes and internal forces of constructed bridges. In this research, by taking the Weihe grand bridge located at Shandong Province, China as construction background, the specific targets and methods of bridge construction control were introduced for the reference of bridge construction and research.*

Keywords: *Large-span variable cross-section; Cantilever construction; Continuous girder bridge; Construction monitoring*

1. Introduction

Construction monitoring refers to the measurement and monitoring of stress and strain of stressed sections, deformation of main measuring points and stresses on main components in bridge construction processes. It is a series system integrating calculation result analysis, monitoring and feedback control of bridge structures in practical construction process by using structure testing and field analysis techniques [1-8].

According to construction technical specifications and design drawings, it is necessary to conduct construction monitoring of the stress on, and deformation at, cross sections in the bridge construction process so as to ensure structural safety in the bridge construction process, and make the line shapes and dead load stress states of the constructed bridge meet expected values.

2. Construction engineering conditions

K30+598.0 Weihe grand bridge is located 270 m the southeast of Anqiu Zhuangzi village, Huangqibao Road, Fangzi district, Weifang City, Shandong Province, China. On the upper structures of the 5th and 12th on the left and right sides of the bridge, the prestressed concrete continuous girder bridge with variable section measuring 55+100+55 m was adopted; while the lower structural abutment adopted ribbed slabs, bridge piers utilized column piers, pier abutment adopted pile foundation. C50 concrete was applied in the box girder with a 16.5 m wide single carriageway. The single girder used a single-box single-chamber straight web structure with 8 m in width, and 4.25 m long cantilever on both flanges. In addition, the lower part of the box girder was 6.25 m high, the heigh of the mid-span girder was 2.5 m and the girder height change followed a quadratic parabola form; the girder top plate was 30 cm; the thickness of mid-span and lower parts for the girder bottom plate changed from 32 cm to 75 cm, the change in the bottom plate thickness also followed a quadratic parabola form; three thicknesses (55 cm, 85 cm and 100 cm) of the box girder web were adopted, among which, the thickness of Nos. 1 to 4 segments was 100 cm, No. 5 segment had a variable thickness, Nos. 6 to 9 segments were 85 thick, No. 10 segment had a variable thickness, Nos. 11 to 13 segments were 55 cm thick, and the thickness of the web on the cast in-situ section of the side span was 55-95 cm.

The elevation view of the Weihe grand bridge layout is shown in Figure 1 and the standard cross section of the bridge box girder is illustrated in Figure 2.

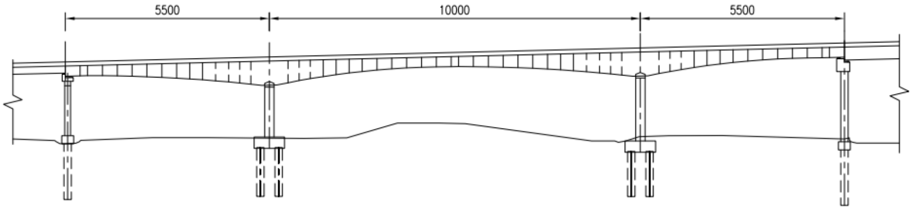

Figure 1: The elevation view of the Weihe grand bridge layout (unit: cm)

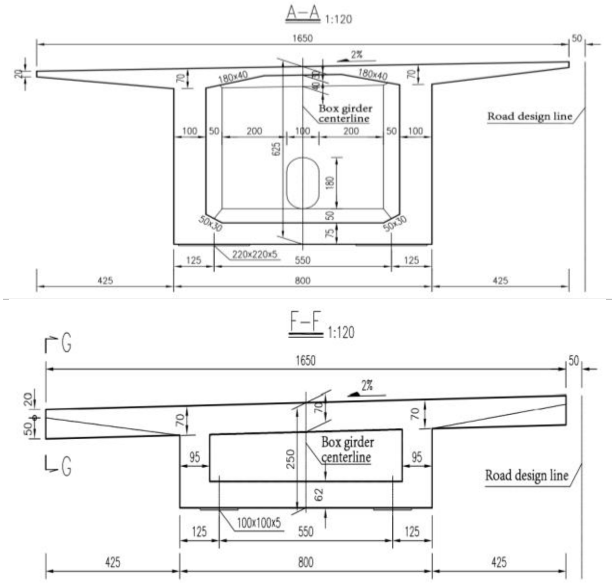

Figure 2: The standard cross section of the bridge box girder (unit: cm)

3. Construction monitoring principle

Construction monitoring aims to realize the effective ocntrol of constructed bridge targest and rectify the parameter errors of various influences on the constructed bridge targets in the bridge construction process on the constructed bridge targets, which can furhter ensure that the structural stress on constructed bridges and bridge line shapes meet designed requirements.

(1) Meeting the stress requirement of on the constructed bridge structure

The main girder is in an elastic state at different construction stages. The internal stress of constructed bridge is in line with the desgined requirements.

(2) Meeting the requirements of the bridge construction process and line shape for construted bridge

The deformation and displacement at the main girder in the bridge construction process should be in a elastic state. The elevation of the main girder in the constructed bridge should satify the design

(3) Ensuring the structural safety and stability of the bridge constrution process

The major construiton scheme of the construction processs should be checked to ensure the structural safety in bridge construction. Early warning must be give timely once potential risks endengering structural safety and stability of the bridge construction are found.

In the bridge construction process, a double-control scheme (namely, control of internal force and the bridge line shape) should be adopted. Besides, the limiting value of some indices exceeding schedueled value should be adjusted. Adhering to the priciple aformentioned throughout the whole construciton process, the structural safety in the construction process and the bridge construction quality can be guranteed.

4. Finite element analysis of construction monitoring

According to the structural dimensions set, reinforcement and construction sequences which were set based on bridge construction drawing design documents, Midas space finite element program and Dr. Bridge software were used for simulation and calculation in the construction process. They were mainly used to simulate and compute structural dead load, phased construction process, temperature change, construction loading, system conversion, as well as effects of phase 2 dead load and live load. Then, based on the bridge construction sequence designed by the construction affiliation, the structural deformation, internal force inside the bridge girder and stress distribution were conducted check calculation. Meanwhile, the camber of supports at different segments and templets was calculated. The calculated structural model of the prestressed concrete continuous girder bridge is shown in Figure 3.

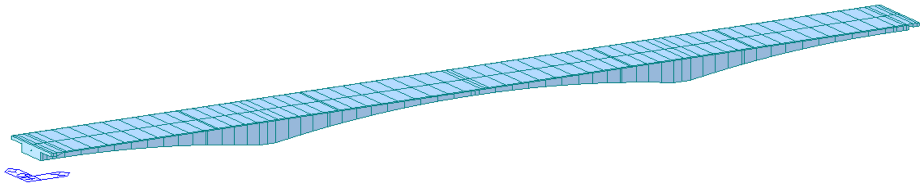

Figure 3: Computational structural model of the prestressed concrete continuous girder bridge

5. Specific construction scheme

5.1 Geometric line shape measurement of the bridge girder

5.1.1. The line shape measurement of the bridge girder

The line shape measurement of the bridge girder mainly includes providing supports at different sections and a camber of templets in the cast-in-situ segmental construction process of the box girder. The key of the measurement is to determine the formwork elevations of currrent coustruction segments prior to cast-in-situ of each segments. The measurements mainly include as follows:

(1) The pire top measurement and setting of reference points

The geodetic control networks on the both sides of the bridge was used. When using a rear intersection point measuring method, Total Station was utilized to measure the three-dimensional coordinates of measuring points on the pier top. The evalation value of the pire top was used as the benchmark point of the girder elevation. There were a horizontal benchmark point and a axial benchmark arranged on the pier top, no less than three measurens are needed in each month. The pier top evevalution obtained at first time was taken as the initial value, the difference between measured value and intitial value under each working condition was considered the displacment of the pier top, as shown in Figure 4.

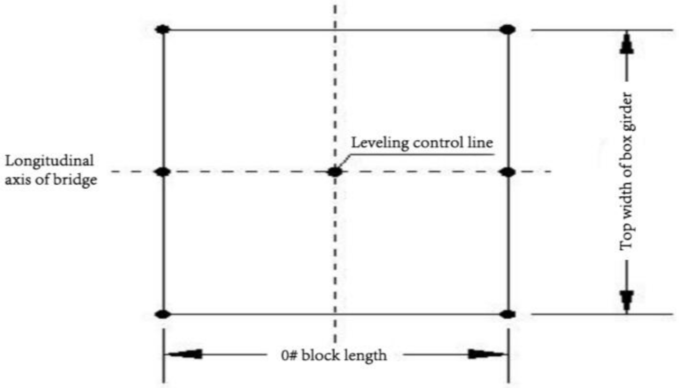

Figure 4: The schematic diagram of the measuring point layout for the elevation of No. 0 block

(2) Monitoring of preloading-induced deformation for supports and hanging baskets

Deformation of the supports subjected to the preloading was monitored and the elastic deformation of the supports was tested, which provided an aid for the determination of the formwork elevation.

In the proloading process of the hanging baskets, the pressure loading and the deformation at the front of the hanging baskets were measured to further plot the curves of loads and deformation of the hanging baskets, which provides data supports to the formwork elevation.

(3) Measurement of the girder deformation

Layout of measuring points: three measuring points were set at the each girder segment 3-5 cm from cantilevered end were set. The measuring points should be pre-buried using bar dowels and labelled using red paint. The center of the pier top and the edge of the upper wing plate were taken as the elevation measuring points of the concrete main girder. Owing to the unevenness of the top surface of main girder in the bridge construction process, the elevation of the girder bottom can only be controlled. Hence, the vertical distances H1-H2 between the measuring points of the top and bottom for the current bridge segment must be measured before removal of the bottom formwork and after casting girder segment concrete, as shown in Figure 5. This can facilitate obtain the evevation of the girder bottom at this measuring position according to calculated evaluation of the measuring points on the top surface of the bridge girder segments, the evevaltion could be measured at vertical prestressed tendons on the bridge girder segments. The head of steel bars must be arranged and coated with red paint at the measuring points on the top of the bridge girder, which warrants reliable support.

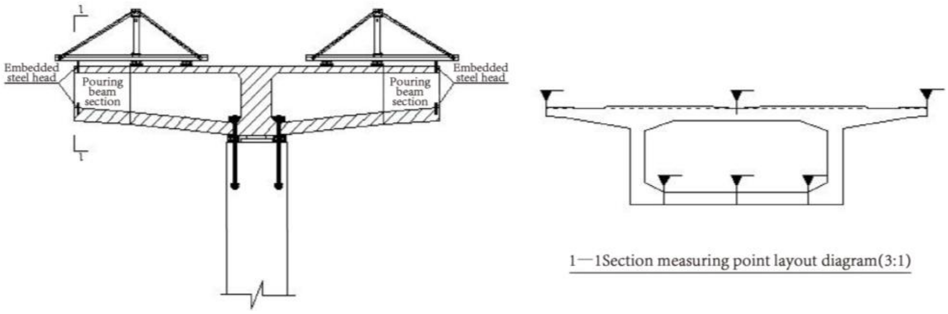

Figure 5: The schematic diagrams of measuring points on the girder section

(4) Control of the construction axis of the main girder

1) Controlling points on No. 0＃block of the main bridge girder are set and introduced in the horizontal control network to be subjected to the overal adjustment. Afterwards, they can act as the fixed controlling points for measurment and testing in the bridge girder construction

2) The girder axis is directly controled by the fixed controlling points, and the Total Station Polar Coordinates are used to directly measure the axial line and detailed structure of each girder segment.

5.1.2. Monitoring of the line shape of bridge piers

There were multiple factors influencing the pier body construction of the primary brdige of the Weihe grand bridge. To ensure the construction quality of the pier body construction,the monitoring of deformation at the piers is required. The pier deformation monitoring includes as follows:

(1) Observaton of the bridge pile cap settlement

The settlement of two main bridge pier caps of the Weihe grand bridge was observed. The settlement and uneven settlement processes of the caps arising from loading during bridge construction were quantitively determined. The observed results could be used to analyze the influence of uneven settlement on the perpendicularity of bridge piers to furhter provide guidance for the construciton control of the brige piers.

Measurement working condition: three permenant observation points were respectively installed at the positions of the triangle in No. 1# and 2# main brider pier caps. Total Station was employed to measure the spatial changes of these points. By using the measure data, the degree of their uneven settlement could be determined. Settlement observation was conducted in every 5 m in height of constructed bridge piers; in addition, seetlement of bridge pile caps on the main bridge girder was observed once after completing two construcitons of each of two sides for the main bridge gierder; furhtermoere, the settlement was implemented after the closure of the whole bridge main girder and completion of the whole bridge construction respectively.

Measuring methods: settlement observations were realized by using Precision Levellers and a indium steel ruler and according to field conditions, use of the geometric leveling or trigonometric leveling methods can be decided.

(2) Displacement testing of the bridge pier top

Tests of the displacement of the bridge pier top and the temperature change were combined to analyze the displacement effects arising from varying temperature and loads on the bridge pier top. By integrating the analyzed results with the calcualtion of the construciton control, the effects of the bridge closure sequence on the displacement on the bridge pier top could be comprehensively analzyed. In combination with design of the bridge pier top, the adjustment scheme was suggested to provide a basis for choosing suitable construction measures (decide whether it is nesseary to adopt pre-jacting force or pre-tension as well as determining right time for applying these forces).

Measuring point arrangement: according to different bridge pier heights, permenant points were buried on the three or four uniformly selected sections on the 1.0 m above No. 1# and 2# bridge pier tops and 1.0 m below No. 0# segment. Their spatial locations of these points were then then monitored.

Measurement workding condition: Observation tiem includes the time after completing the construciton of the bridge pier and before concrete casting on No. 0# segment, and the time before and after construction of the bridge T-structure closures. The observation should be conducted in a same time to ensure the consistence of testing conditions. When temperature change is obvious, the influence of temperature-induced displacement should be considered in data observation.

Measurement methods: measuring points were monitored using the Total Station Polar Coordinate method.

5.2 Monitoring of stress on the bridge girder

Stress (strain) monitoring is an essential content of bridge construction monitoring. It is directly associated with structural safety of bridges, which is an imporatn index that determines construction safety. A comparision between measured stress values and theoretical values can be used as an essential basis for judging that whether the working state of brige structures is able to meet desgin and specification requirements. The stress (strain) monitoring of the bridge researched in this work was achieved by a embedded-strain-gauge technique.

The selection of testing sections and sensor arrangement of testing sections were described as follows:

(1) Sections of pier tops and pier bottom

The strain components on the section of the pier bottom were mainly used to monitor whether cantilever beams are in a cantilever construction state in the bridge consruction process.

(2) Section of the lower part of the box girder.

The strain components installed on the section of the lower part of the box girder were primaryly adoptedto monitorthe stress inside the girder in the construction process.

(3) Section of the closure segment

The strain compoents on the section of the closure segment were mainly used to monitor the prestension in the later constuction stage and the stress condition inside the bridge girder subjected to a constant load.

The measuring point layout on the section of the bridge girder is dispalyed in Figure 6. A vibrating wire strain gauge installed could be simultaneously for construction monitoringlong, static load testing of completed bridge and long-term observations of bridge operation.

Stress measurement methods: the stress on the main girder monitoring was measured by burying a vibrating wire strain gauge inside the concrete. The change in the frequency of the vibrating wire strain gauge could be used to measure the strain on the bridge girder so as to further obtain the stress on the girder.

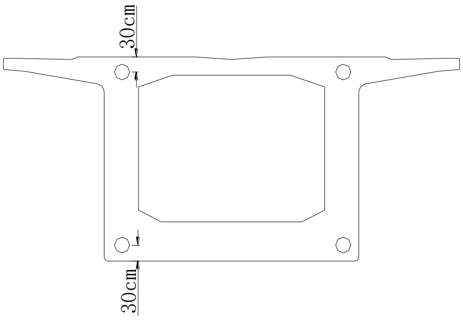

Figure 6: The layout of strain measuring points on the girder control section

5.3 Ambient temperature monitoring

Ambient temperature was measured using a mercury thermometer with a measurement accuracy of ±0.5 °. Structural deformation and displacement of the bridge girder were measured, in the meanwhile, the ambient temperatures of bridge girder structure under the strong sunshine and other unchanging construction conditions were daily measured at 7:00 am, 14:00 pm and 17:00 pm. The measurement data were recorded to further drawn the temperature curves.

The measuring point layout of temperature was same to that of stress. As the temperature memory type strain sensors were installed on the stress measuring points, so there was no need to set other stress measuring points.

Since temperature data could be obtained when each strain measurement was performed, the temperature measurement was therefore conducted along with strain measurements.

6. Conclusion

A reasonable construction control scheme is considered a primary safety and quality guarantee of bridge construction. The Weihe grand bridge was completed and currently open to traffic. All construction requirements all meet the design standards. In addition to reasonable and good construction technique, well-developed construction monitoring scheme plays an essential role. Therefore, bride construction control warrants our sufficient attention so as to better serve for bridge construction.

References

[1] Xiao Gang. Research on Key Technologies of Continuous Box Girder Bridge Cradle Construction Monitoring [J]. China Standardization, (2018) (04), 98-100

[2] Zhu Hongjun. Research on Finite Element Modeling and Construction Monitoring of Prestressed Variable Section Continuous Box Girder Bridge [J]. Heilongjiang Transportation Science and Technology, (2018) 41(02), 119-120.

[3] 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

[4] Wu Wenhui. Research on construction technology and construction monitoring of cantilever hanging basket pouring of a continuous box girder bridge [J]. Heilongjiang Transportation Science and Technology, (2017) 40(02), 91-92+94.

[5] Jia Zhongtao, Wang Lifeng, Zhang Yan. Construction Monitoring Scheme for Prestressed Concrete Continuous Box Girder Bridge [J]. Heilongjiang Transportation Science and Technology, (2012) 35(12), 80-81.

[6] Deng Liang, Yang Meiliang, Tan Hailiang. Research on Construction Monitoring Technology of Changlian Multi span Continuous Box Girder Bridge [J]. Highway Engineering, (2012) 37(05), 165-167+175

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

[8] Zuo Dengfa. Research on Construction Monitoring Technology of Concrete Continuous Box Girder Bridge [J]. Engineering and Construction, (2009) 23(02), 243-245