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Original Paper

Construction Monitoring and Results Analysis of a Certain Major Bridge

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Abstract

The construction method of continuous beam bridges is mostly cantilever casting in place, which has a long construction period and complex process, and is influenced by various factors. Therefore, it can have many adverse effects on the internal forces and deformation of the main beam. To ensure that the line shape of the main beam meets the design and regulatory requirements and that the internal forces of the completed bridge are close to the theoretical design values, ensuring the safe construction of the bridge, it is necessary to monitor the entire construction process of the bridge. This paper takes a certain major bridge as the background, monitors the entire construction process of the main bridge, collects the deflection values at control points and stress values at control interfaces at each construction stage, and compares the measured values with theoretical results. This allows for a comprehensive understanding of the line shape changes and safety conditions of the bridge, assures the reliability and safety of the structure during construction, ensures that the relative elevation deviation of the closure section is less than the permitted values by standards, and makes sure that the line shape of the main beam after completion meets the design specifications.

Keywords

Major bridge, Construction monitoring, deflection value; stress value

1. Introduction

Prestressed concrete continuous beam bridge has many advantages such as small deformation, beautiful line shape, easy maintenance, comfortable driving and good seismic performance. Therefore, it has become the main bridge type in urban bridge, highway bridge and railway bridge construction. Prestressed concrete continuous beams are mostly box girders with variable cross-sections, and the thickness of webs, bottom plates and top plates generally changes gradually with the span. Due to its strong spanning ability, prestressed concrete continuous beam bridge has more significant advantages within 150 meters of span than other types of bridges, and its construction technology is relatively mature, so it is widely used in bridge construction.

During the construction process, there are many errors that cause the structural state to deviate from the design ideal state. In the adaptive theory construction control system, these errors are generally divided into three categories: construction error, measurement system error, and structural parameter error. The design ideal state will also be adjusted continuously according to the state error. During the construction of the main beam, the actual state of the main beam is measured on site and compared with the design ideal state. If there is no error or the error is small, the construction proceeds to the next stage. If the error between the actual state of the main beam and the design ideal state is large, the error is analyzed. Firstly, the parameter error identification analysis is carried out, and the identified parameters are substituted into the finite element calculation model for recalculation to obtain a new ideal state of the main beam. According to the analysis results, the control quantity in the construction is adjusted. This process is repeated at each construction stage until the error is eliminated or the bridge construction is completed. The background project studied in this paper is Xinye Baihe Bridge, which is a long-span prestressed concrete continuous beam bridge. The construction process is cantilever cast-in-situ with a suspended formwork, and the construction stages have strong repetitiveness. Therefore, an adaptive control method is used for full-bridge construction monitoring.

2. The Composition of the on-site Monitoring System

The construction control system of the cantilever construction process for prestressed concrete continuous beams primarily consists of three major components: the real-time measurement system, the on-site testing system, and the construction control calculation system.

(1) Real-time measurement system

The core of the construction control system is the real-time measurement system. By collecting data from real-time measurements, it comprehensively masters the current stress state and deformation condition of the bridge during the construction phase, serving as the most critical guide for bridge construction. Ensuring its reliability and accuracy is essential. In the construction of prestressed concrete continuous beams, real-time measurement mainly includes monitoring the elevation of the main beam, concrete strain, construction time, and the temperature of the box girder, among others.

(2) On-site testing system

During the construction control process of prestressed concrete continuous beam bridges, it is necessary to obtain on-site test parameters and to use these measurements to adjust the parameters of the finite element model. This adjustment aims to make the computational model as congruent as possible with the actual state of the main beam. The collected and measured data on-site typically includes the elastic modulus of the box girder's concrete, the concrete's unit weight, the actual section and geometric dimensions of the box girder, construction loads, crowd and equipment loads, form traveler load, and formwork self-weight, etc.

(3) Construction control calculation system

The construction control of a prestressed continuous beam bridge involves a cyclical process of first predicting the structural state, then building, followed by measuring the construction results, identifying calculations based on the measurement outcomes, and then making further predictions based on the calculated results. Throughout monitoring, it ensures that the linear shape, internal forces, and elevation difference in the closure section of the main beam stay within the prescribed error range. Thus, after closing the gap, the main beam's linear shape is satisfactory, in compliance with design and specification requirements, and the construction process is safe and reliable. The construction control calculation system refers to analyzing errors in structural calculation parameters, operational errors arising during construction and measurement processes, and inherent inaccuracies in the structural analysis model itself that affect the state of the main beam structure. It involves identifying and obtaining true values for the structural parameters based on the errors, utilizing identified parameter values for feedback calculations, and employing new theoretical values to predict the construction precamber for the next segment.

3. Line Shape Monitoring Results and Analysis

3.1 Beam Displacement Analysis

Line shape control is a key factor in construction monitoring. During the cantilever construction process of prestressed concrete continuous beams, after the concrete is poured, the beam will undergo downward deflection deformation. After the prestressing tendons are tensioned, the beam will then experience upward deflection deformation. Throughout the construction process of each standard block segment, after the completion of each construction procedure, it is necessary to measure the elevation of the cantilever end of the beam. The deformation value of the beam under that procedure can be obtained by comparing the elevation measured in the current procedure with the elevation measured in the previous procedure. As the displacement of the beam caused by concrete pouring and prestressing tensioning is relatively large compared to the displacements in other procedures, only the displacements of the beam after concrete pouring and prestressing tensioning for each standard construction block segment are compared and analyzed, while the displacements in other procedures are not analyzed. At each construction stage, errors between the actual deflection measurements and theoretical deflection values are compared and analyzed. Based on the analysis of these errors, predictions for the deflection of the main beam in the next construction phase are made, and adjustments to the construction camber are carried out.

Below, using the right abutment pier number 7 as an example, Table 1 lists the theoretical and actual displacement values of the cantilever end head of the main beam after concrete pouring and prestressing tendon tensioning, from block 1 to block 15. With the pouring of the concrete of each standard block segment, the downward displacement of the beam progressively increases, with the maximum measured displacement being approximately 47.8mm. Similarly, as prestressing is applied at each construction stage, the upward displacement of the beam gradually increases, with the maximum measured displacement being approximately 18.7mm.

Table 1. Right Span Pier #7 Main Beam Displacement at Each Construction Node

Stage	Condition	Theoretical Deformation Value (mm)	Measured Value (mm)	
			East Side	West Side
1#	after pouring	-0.9	1	-0.7
	after tensioning	0.3	1	1
2#	after pouring	-1.6	-2.3	-2.1
	after tensioning	0.6	1.1	1.5
3#	after pouring	-2.5	/	-5.9
	after tensioning	1	1.4	1.5
4#	after pouring	-3.8	-1.7	-6.3
	after tensioning	1.5	1.9	/
5#	after pouring	-5.4	-6.96	-10.7
	after tensioning	2.1	/	/
6#	after pouring	-7.3	-3.9	-9.1
	after tensioning	2.8	3.1	2.2
7#	after pouring	-9.4	-7.4	-15.7
	after tensioning	3.6	6.9	4.5
8#	after pouring	-11.8	-9.5	-17.7
	after tensioning	4.5	5.9	5.5
9#	after pouring	-15.3	/	-16.7
	after tensioning	5.9	8.4	5.4
10#	after pouring	-19.3	-22.9	-22.1
	after tensioning	7.4	7.7	6.7
11#	after pouring	-23.7	-15.2	-28.6
	after tensioning	9.1	10.9	12.4
12#	after pouring	28.5	-20.7	-30.9
	after tensioning	10.9	9.5	/
13#	after pouring	-32.6	-26.2	-37.5
	after tensioning	12.5	12.7	15.3
14#	after pouring	-39.6	-33.23	-43.4
	after tensioning	15.2	16.7	17.7

15#	after pouring	-45.8	-37.1	-47.8
	after tensioning	17.2	18.2	18.7

3.2 Closure Error Analysis

The sequence of closing the main beams involves first connecting the side spans and then the middle span. Prior to the side span closure, the closure sections are weighted with water tanks. Continuous monitoring of the elevations at both ends of the closure section is conducted before concrete pouring, until the elevation difference between the two ends stabilizes. Subsequently, a stiff skeleton is welded, and prestressed steel strands are fixed in place. The concrete operations for the closure section are scheduled to take place during the coldest time of day, from 4:00 a.m. to 6:00 a.m. In compliance with error control standards, the elevation differences for the closure sections of Baihe Grand Bridge are recorded in Tables 2 and 3. All errors were within the permissible range of the specifications, and the line shape of the main beam after closure was good, meeting the design and specification requirements. This successfully fulfilled the construction monitoring task for Baihe Grand Bridge, achieving the anticipated objectives.

Table 2. Side Span Closure Segment Error (units: m)

Closure Construction Segment		**Design Elevation**	**Measured Elevation**	**Design Camber**	**Error**
right span of pier #7 side span	east side	97.842	97.851	0.000	0.009
	west side	97.886	97.892	0.000	0.006
right span of pier #8 side span	east side	100.155	100.167	0.000	0.012
	west side	100.146	100.141	0.000	-0.005
left span of pier #7 side span	east side	97.842	97.849	0.000	0.007
	west side	97.886	97.878	0.000	-0.008
left span of pier #8 side span	east side	100.155	100.164	0.000	0.009
	west side	100.146	100.151	0.000	0.005

Table 3. Mid-Span Closure Segment Error (units: m)

Closure Construction Segment		**Design Elevation**	**Measured Elevation**	**Design Camber**	**Error**
Right span Mid-span	east side	99.843	100.007	0.150	0.014
	west side	99.861	100.018	0.150	0.007
left span Mid-span	east side	99.843	100.002	0.150	0.009

	west side	99.861	100.022	0.150	0.011

4. Stress Monitoring

Another important aspect of construction monitoring for continuous beam bridges is stress monitoring, which serves as the basis for assessing safety risks during the construction process of the main beam. The stress at any point in the structure changes as construction progresses. Stress monitoring in construction control involves observing and comparing the actual stress within the beam at a certain construction stage versus the theoretical stress, and determining if the main beam structure is in a safe state based on the monitoring results. For the Baihe Grand Bridge, stress monitoring was conducted at various control sections of the main beam, including the sections at the base of the box girder, the 1/4 section, the 3/4 section, and the closure segment section. Concrete strain gauges were embedded in these sections to observe stress changes and distribution throughout the construction process and to compare them with theoretical computed values. This allows for forecasting the safety status of the main beam at the current stage of construction. The purpose of stress monitoring for this bridge is to ensure that the main beam remains safe and reliable during construction and that the internal forces within the main beam after completion meet the design requirements.

When utilizing testing instruments to measure the stress on main beams, errors inherent to the instruments, environmental interference, and human operational errors can lead to field-measured stress data being higher than the actual stress within the beam. This could create a false impression that the beam has sustained damage, thus affecting the judgment of the beam’s true stress state. The factors contributing to these errors mainly include: concrete shrinkage and creep, temperature effects on box girders, errors from theoretical calculations, and errors inherent to the testing system itself. Among these, concrete shrinkage and creep as well as temperature effects on box girders are particularly influential on test data. During construction monitoring, strain sensors measure the strain in concrete to calculate the stress on the main beam sections at various construction stages. However, concrete shrinkage and creep, along with temperature effects, can cause the concrete within the box girder to shrink or expand, resulting in significant deformation. Consequently, the strain data collected includes not only the strain caused by various construction loads but also the deformation due to shrinkage, creep, and thermal effects, leading to measured stresses that are higher than the actual stresses in the beam. Therefore, after obtaining the strain data from the concrete on-site, it is necessary to adjust for the shrinkage, creep, and temperature effects at that construction stage to ascertain the true stress within the beam. The true stress should then be compared with theoretical stress to assess the beam’s safety and its behavior under temperature variations.

The stress on the main beam at each construction stage of the Baihe Grand Bridge has been tested and compared with theoretical values to prevent safety accidents during the construction process. Table 4 shows the comparison between the tested stresses and theoretical stresses at the control section of the right side 7# pier box girder. From the test results, it can be observed that the measured stress variation trends on the upper and lower edges of the control section are completely consistent with the theoretical trends. The measured stress values on both edges are slightly higher than the theoretical values. This is due to the presence of measurement errors and temperature effects, even though the testing error caused by shrinkage and creep has been considered during measurement. As a result, the measured stress values are higher than the theoretical values. Throughout the entire construction process, the cross-section of the main beam is under compression, with the maximum measured compressive stress being 12.3MPa, which is below the standard compressive strength value of C55 concrete (35.5MPa). This ensures the safe construction of the main beam.

Table 4. Test Results for the Root Section of the Right Side 7# pier Box Girder)

Stage	Condition	Upper Edge (units:MPa)		Lower Edge ((units:MPa)	
		Theoretical Value	Measured Value	Theoretical Value	Measured Value
1#	after pouring	0.2	/	-0.2	/
	after tensioning	-1.1	-0.9	-0.2	/
2#	after pouring	-0.9	-0.7	-0.4	-0.6
	after tensioning	-2.5	-2.8	-0.3	-0.4
3#	after pouring	-2.0	-2.3	-0.6	-0.9
	after tensioning	-3.9	-3.7	-0.4	-0.6
4#	after pouring	-3.3	-3.6	-0.9	-1.1
	after tensioning	-5.3	-5.9	-0.6	-0.8
5#	after pouring	-4.5	-5.2	-1.2	-1.5
	after tensioning	-6.4	-6.9	-0.9	-1.1
6#	after pouring	-5.5	-5.8	-1.7	-2.2
	after tensioning	-7.4	-8.1	-1.3	-1.6
7#	after pouring	-6.5	-6.9	-2.1	-2.5
	after tensioning	-8.3	-8.8	-1.8	-2.1
8#	after pouring	-7.1	-7.5	-2.9	-3.2
	after tensioning	-8.9	-9.7	-2.6	-2.9
9#	after pouring	-7.6	-8.1	/	-4.4
	after tensioning	-9.4	-10.9	-3.4	-3.7
10#	after pouring	-8.0	-9.2	-4.7	-5.3
	after tensioning	-9.9	-11.2	-4.3	-4.7
11#	after pouring	-8.4	-9.9	-5.7	-6.8
	after tensioning	-10.2	-11.4	-5.3	-5.9

12#	after pouring	-8.6	-10.3	-6.8	-7.7
	after tensioning	-10.4	-11.8	-6.4	-6.9
13#	after pouring	-8.6	-10.9	-8.0	-9.2
	after tensioning	-10.4	-12.1	-7.6	-8.5
14#	after pouring	-9.3	-11.4	-9.3	-10.4
	after tensioning	-10.3	-11.9	-8.9	-9.8
15#	after pouring	-9.9	-11.7	-9.4	-10.8
	after tensioning	-10.6	-12.3	-9.2	-10.4

5. Conclusion

This article mainly introduces the specific implementation process of construction monitoring for the main bridge of Baihe Grand Bridge. The establishment of an on-site construction monitoring system, including linear monitoring and stress monitoring, is conducted, and the results of on-site monitoring are analyzed.

The composition of the on-site monitoring system for Baihe Grand Bridge is described, which mainly includes a real-time measurement system, on-site testing system, and design calculation system. The arrangement of measurement points, testing time, and testing content for linear monitoring are detailed, and the test results are compared and analyzed against theoretical values. During the cantilever construction and closure stage, the linear error of the main beam is within the reasonable range required by specifications. The maximum closure error in the closure section is 14mm, meeting the closure requirements. After the completion of the bridge, the main beam has a good shape that matches the design, achieving the overall objectives of construction monitoring.

In terms of stress monitoring, the selection of testing instruments, the arrangement of testing sections and measurement points are briefly introduced. The testing time and content are explained, and the test results are statistically analyzed. From the test results, the actual stresses on the main beam during each construction stage are basically consistent with the theoretical stresses. Both the upper and lower edges of the main beam are under compression, without any tensile stress. The maximum measured compressive stress is 12.3MPa, which is less than the standard compressive strength value of C55 concrete (35.5MPa), indicating that the main beam is safe and reliable during the actual construction process.

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