Article

Construction Control and Monitoring Platform of a Large-Segment Steel Box Girder with Hoisting Installation

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Abstract: The large-segment hoisting construction technology for bridges is increasingly widely used due to its flexibility and efficiency, although it also poses challenges to construction monitoring. Traditional monitoring technology is unitary with low data processing efficiency, making it difficult to meet the accuracy requirements of large-segment hoisting. The application of digital technology has brought about an opportunity for innovation in bridge construction monitoring technology. To address existing challenges and explore digital applications, this paper takes the integral hoisting construction control of the large-segment steel box girder in a large cross-sea bridge as an example, developing an alignment, stress, and temperature monitoring scheme by taking the key points of hoisting construction control into consideration. A monitoring platform was developed, and the workflow of large-segment hoisting construction monitoring is systematically summarized from the viewpoint of practical engineering, which provides a valuable reference for achieving precise and efficient construction monitoring and control in similar projects.

Keywords: large-segment steel box girder; integral hoisting; construction monitoring; state control; digital technology

1. Introduction

Bridge construction, as an important component of transportation infrastructure, has gained more and more attention with the development of large bridge spans; increased complexity of bridge structures; and growing awareness of driving safety and the gradual development of new materials, intelligent perception, and big data technology. Thus, the gradual development of bridge construction control, as an indispensable link in bridge construction, operation, and maintenance, has been of increasing significance, running through the entire bridge life cycle [1–3]. The multiple impacts from both the environment and construction would make the monitored data deviate from the designed ideal state of the bridge. It is crucial for bridge construction and management to obtain values relatively close to ideal values from monitored data, analyze the actual state of the bridge, and predict future states [4].

In recent years, the hoisting construction of a large-segment steel box girder which can install beams exceeding 100 m at a time has become highly popular in bridge engineering, particularly under challenging cross-sea or cross-river natural conditions and complex urban environmental conditions [5,6]. Typical cross-sea projects include Japan’s Tokyo Bay Cross-sea Bridge [7] and Denmark’s Great Belte Strait East Bridge Approach Bridge [8]. After these, Su-Tong Yangtze River Bridge [9], Chong’qi Bridge [10], and non-navigable span bridges in deep water area of Hong Kong-Zhuhai-Macao Bridge [11] came into being. Large-segment hoisting has many advantages, such as a short construction period, high construction safety, and strong adaptability to the environment. With this construction method, a large-segment steel box girder must go through many stages, such as factory
manufacturing, field installation, and bridge connection. Therefore, the geometric state of the bridge will change greatly in each construction stage, resulting in multiple alignments that are difficult to control. In addition, it is difficult to adjust the alignment in the large-segment hoisting process through the cushion block or weld width, which can only be used in the small-segment hoisting process. With the continuous increase of modern bridge spans, the accuracy of large-segment steel beam manufacturing, the precision requirements of hoisting positioning, and the difficulty of alignment monitoring are all improved. From the perspective of beam manufacturing to hoisting positioning and even operation and maintenance in the future, the task of construction monitoring becomes particularly important [11–17]. However, the monitoring technology of large-segment construction is not mature enough. A standardized monitoring system has not been established, and the monitoring scope is not clear enough. Some construction monitoring methods are difficult to adapt to the complex and changeable construction environment, or can only monitor a part of the bridge, resulting in the absence of integral response collection [18]. A large number of monitoring data need to be analyzed and processed in order to find and solve problems in time. However, the lack of data processing and analysis ability of the monitoring system at present leads to the low utilization rate of monitoring data, a lag of information, and delays in decision-making. It is still a topic full of opportunities and challenges to identify how to better utilize digital technology, combine contemporary cybernetics with large-segment hoisting construction, encourage the renewal of monitoring instruments, speed up information transmission and processing [19], and improve the effectiveness and accuracy of monitoring systems.

Based on the background described above, this paper relies on the large-segment hoisting construction monitoring work of the large cross-sea bridge (Xiang’an Bridge) shown in Figure 1; summarizes the general process and method of hoisting monitoring of large-section steel box girders; and introduces the key points of hoisting construction control of large-section steel box girders and the corresponding alignment, stress, and temperature monitoring scheme. In conjunction with digital technology, real-time monitoring and control of construction are conducted through finite element simulation and analysis of the parameters gathered on site, which ensures the smooth progress of construction and serves as a reference for similar projects.

Figure 1. Xiang’an Bridge (Xiamen, China).
2. The Content of Monitoring of Large-Segment Hoisting in the Large Cross-Sea Bridge

2.1. Project Overview

The total length of the sea-crossing steel box girder project of the large cross-sea bridge is 3.27 × 10^3 m, including four main parts of three navigation channel bridges (West Navigation Channel Bridge, Middle Navigation Channel Bridge, East Navigation Channel Bridge), the Huandao East Road Interchange Main Line Bridge, the West Non-Navigable Channel Bridge, and the East Non-Navigable Channel Bridge, as detailed in Table 1. The standard span layout is arranged as 4 × 90 m, and the main girder adopts an orthotropic steel deck steel box girder, with a 37 m beam girder width and a 3.5 m beam height. The construction of steel box girders adopts the scheme of large-segment lifting with a floating crane. The manufacture consists of three stages: plate element manufacturing, small segment fabrication, and large segment assembly, all of which are completed in the factory. After the large segments are fabricated, the beam segments are lifted onto the transportation ship using floating cranes and transported to the bridge site for installation. The maximum lifting length for the standard joint is 108 m, and the maximum segment weight for lifting is 2.7 × 10^6 kg.

Table 1. Overview of steel box girders in the sea of the large cross-sea bridge.

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Span Composition</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huandao East Road Interchange Main Line Bridge</td>
<td>4 × 90 m</td>
<td>Steel box girder with variable width</td>
</tr>
<tr>
<td>West Non-Navigable Channel Bridge 1</td>
<td>5 × 90 m</td>
<td>Steel box girder with constant section</td>
</tr>
<tr>
<td>West Navigation Channel Bridge</td>
<td>4 × 90 m</td>
<td>Steel box girder with constant section</td>
</tr>
<tr>
<td>West Non-Navigable Channel Bridge 2</td>
<td>4 × 90 m</td>
<td>Steel box girder with constant section</td>
</tr>
<tr>
<td>Middle Navigation Channel Bridge</td>
<td>2 × 90 + 2 × 150 + 2 × 90 m</td>
<td>Steel box girder with variable height</td>
</tr>
<tr>
<td>East Non-Navigable Channel Bridge 1</td>
<td>4 × 90 m</td>
<td>Steel box girder with constant section</td>
</tr>
<tr>
<td>East Non-Navigable Channel Bridge 2</td>
<td>4 × 90 m</td>
<td>Steel box girder with constant section</td>
</tr>
<tr>
<td>East Navigation Channel Bridge</td>
<td>4 × 90 m</td>
<td>Steel box girder with constant section</td>
</tr>
</tbody>
</table>

2.2. The Main Work of Construction Monitoring

Based on different construction states, construction monitoring can be divided into the preparation stage, prefabrication stage, installation stage, post-installation, and bridge operation and maintenance stage, as shown in Figure 2. On this basis, a perfect monitoring system has been established, combined with digital technology.

Based on the structural configuration and construction technology characteristics of Xiang’ian Bridge, the following four aspects of work will be carried out with the aim of construction control: (1) analysis of structure state during construction: determine the ideal construction parameters by comparing the structure state during construction with design calculations; (2) monitoring the key parameters in the structure during construction: monitor the deformations and stresses of the steel box girders; (3) analysis and adjustment of construction errors: analyze the linear errors during the installation of the steel box girders and adjust errors which exceed the control values; (4) prediction of subsequent construction state: predict the subsequent states of the bridges based on the current state and ensure the realization of the designed bridge state.
Figure 2. Main work and digital monitoring system of the lifting construction monitoring of the large-segment steel box girder of the large cross-sea bridge.
3. Analysis of Construction Monitoring Challenges

As a newly emerged and efficient construction technique, the large-segment lifting method unavoidably presents various challenges and features compared to traditional construction methods. Therefore, its monitoring and control technology has not yet matured. The complexity of construction and precision requirements of the large cross-sea bridge project pose the following challenges for monitoring work:

(1) Accurate prediction of mechanical behavior of steel box girders [7,10]

During the process of assembly and on-site hoisting, steel box girders experience continuous variations in support boundaries, construction loads, and structural systems, leading to changes in both deformation and stress states. Accurately predicting various mechanical behaviors of the steel box girder presents one of the challenges in monitoring steel box girder construction.

(2) Temperature impact [11,20]

Steel structures exhibit high thermal conductivity and are susceptible to temperature variations, not only in their entirety, but also locally due to solar radiation. Variations in temperature and their gradient patterns may lead to further stress and deformation in the structure, with higher temperature differences having a more significant impact on the stress linearity of the steel box girder. The challenge also lies in controlling temperature fluctuations during the segment assembly and hoisting process while properly assessing the temperature impact and mitigating it in a timely fashion.

(3) Pre-set angle of steel box girder [6]

The construction of steel box girders involves segmental assembly with numerous welds, and the attainment of a smooth and linear beam section requires the pre-setting of the angle at the end section. However, due to the variations in section height and width and the large number of segments, different pre-set angles are required for each section. Therefore, ensuring the appropriate setting of the pre-set angle during construction monitoring poses a significant challenge.

(4) Accurate connection control between steel box girder segments [6,21]

The large segments of the steel box girder are connected by bolt welding, and the adjustable range of bolt connection is much smaller than that of weld connection (only a 2 mm adjustment). To ensure accurate connection between large segments, precise control of the linearity of the steel box girder is necessary. Accurately predicting and controlling the linearity of the steel box girder will be a monitoring challenge for this project, due to the considerable interference of external factors such as temperature and wind speed on the linearity of non-navigable hole steel box girders.

4. Numerical Simulation

Focusing on the content and challenges of monitoring of large-segment hoisting in the large cross-sea bridge, this section will conduct a finite element modeling and analysis of the engineering practice on the Xiang’an Bridge. The structural response under typical working conditions is discussed and parameter sensitivity analysis is carried out. Furthermore, the simulation results will be used to guide the construction and will also be compared with the monitoring results to ensure the smooth progress of the project.

4.1. Establishment of FE Model

(1) Mesh generation

Commercial FE software, Midas Civil 2020, was utilized to perform a simulation and analysis of the construction process for hoisting installation. Here, the steel box girders were modeled using 3D beam elements and meshed based on the positions of diaphragms and supports along the longitudinal direction of the bridge. The entire model comprised a total of 207 elements and 252 nodes. Certain construction details, such as diaphragms,
lifting points, and temporary facilities, were simplified and treated as concentrated loads to assess their respective impacts. Layout of the model elements and standard cross-section are shown in Figures 3 and 4, respectively.

**Figure 3.** Finite element model (span arrangement: $4 \times 90$ m).

![Finite element model](image)

**Figure 4.** Standard cross-section of the steel box girder: (a) geometry layout (unit: mm); (b) FE model.

(2) Boundary

Figure 5a,b show the simulation of the temporary corbel connection and support of the bridge, respectively. The nodes, which were arranged at the support positions according to the design scheme, were rigidly connected to the corresponding nodes of the beam body using a rigid connection. Meanwhile, the corresponding translational displacement was restrained at the support. Based on the specialized construction and installation plan of the steel box girder, the temporary supports were arranged during the construction process and the time of the system conversion was determined. When the hoisting work of the steel box girder was done, the temporary corbel connection was set, connecting with the former girder.

**Figure 5.** Simulation of the temporary corbel connection and support. (a) Temporary corbel connection; (b) support.

(3) Construction conditions

This paper presents the simulation of the hoisting construction process of a four-span continuous steel box girder under six different construction conditions. The hoisting order of each span is shown in Table 2.
Table 2. Description of construction conditions.

<table>
<thead>
<tr>
<th>Construction Sequence</th>
<th>Hoisting of Large-Segment Steel Box Girder</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hoisting of 108 m steel box girder</td>
</tr>
<tr>
<td>2</td>
<td>Hoisting of 90 m steel box girder</td>
</tr>
<tr>
<td>3</td>
<td>Hoisting of 90 m steel box girder</td>
</tr>
<tr>
<td>4</td>
<td>Hoisting of 72 m steel box girder</td>
</tr>
<tr>
<td>5</td>
<td>Remove temporary load</td>
</tr>
<tr>
<td>6</td>
<td>Apply pavement load</td>
</tr>
</tbody>
</table>

During the hoisting process from the second to the last span, each step was further divided into two stages, according to the construction sequence specified in the design.

A. The hoisting span was connected to the former span by temporary corbel connection.

B. The rigid connection formed after welding.

The typical construction conditions are shown in Figure 6.

Figure 6. Typical construction conditions.

4.2. Results and Discussion

Using the non-navigable span of Xiang’an Bridge as an example, Figures 7 and 8 illustrate the stress distribution of the top and bottom plates, while Figures 9 and 10 show the displacement results. The maximum stresses of the top and bottom plates are 13 (−60) MPa and 105 (−19) MPa, respectively, which are within the allowable range. The vertical maximum deflection is 175 mm, less than 2‰ of the span. Moreover, the overall distribution trend and numerical level of stress and deflection are consistent with similar projects [3,13]. These preliminary numerical simulations provide a theoretical foundation and data support for stress and deformation monitoring during the construction process of large-segment steel box girders, which are key aspects of the digital construction monitoring process for Xiang’an Bridge.
4.3. Parametric Sensitivity Analysis

4.3.1. Sensitivity Analysis of Bulk Density

The influence of bulk density error on deformation.

Based on a 5% error in bulk density calculation, taking the East Non-Navigable Channel Bridge 1 as an example, calculate the deformation of 1# and the completion condition of the bridge. Taking a 5% increase in bulk density, the deformation reaches 3.9% of the mid-span deformation. The deformation under various working conditions is shown in Figures 7, 8, and 9. The influence value of bulk density changes on the mid-span deformation is shown in Table 3. When lifting the 1# span, the variation of mid-span deformation is 3.3% to 3.6%. The deformation under various working conditions is shown in Figures 7, 8, and 9.

Figure 7. Stress distribution of top plate in the first span.

Figure 8. Stress distribution of bottom plate in the first span.

Figure 9. Displacement of the first span for the non-navigable bridge.

Figure 10. Displacement of the total span for the non-navigable bridge.
4.3. Parametric Sensitivity Analysis

During bridge construction, errors often occur, leading to significant or minor deviations in the actual structural conditions. To address this issue, performing a parametric sensitivity analysis of theoretical models becomes crucial. This section focuses on large-span steel box girders, using the East Non-Navigable Channel Bridge 1 as an example. The main goal is to analyze the impact of three parameters: the weight of the steel box girder, the elastic modulus, and the temperature on the structure’s internal forces and deformation.

4.3.1. Sensitivity Analysis of Bulk Density

(1) The influence of bulk density error on deflection

Based on a 5% error in bulk density calculation, taking the East Non-Navigable Channel Bridge 1 side as an example, calculate the deflection changes during the lifting condition of 1# and the completion condition of the bridge. Taking a 5% increase in bulk density as an example, the variation value of mid-span deflection is shown in Table 3. When lifting the 1# span, the variation of mid-span deflection reaches 3.9% of the mid-span deflection. When the bridge is completed, the deflection variation of mid-span deflection in each span is 3.3% to 3.6%. The deformation under various working conditions is shown in Figures 11 and 12.

Table 3. The influence value of bulk density changes on the mid-span deflection value.

<table>
<thead>
<tr>
<th>Construction Conditions</th>
<th>Lifting the 1# Span</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mid-Span of 1#</td>
<td>Mid-Span of 2#</td>
</tr>
<tr>
<td>Original deflection (mm)</td>
<td>−196.2</td>
<td>−120.1</td>
</tr>
<tr>
<td>Deflection (mm)</td>
<td>−203.9</td>
<td>−124.5</td>
</tr>
<tr>
<td>Rate of change (%)</td>
<td>3.9%</td>
<td>3.6%</td>
</tr>
</tbody>
</table>

Figure 11. Vertical deflection change of the first span steel box girder caused by bulk density.

(2) The effect of bulk density error on stress

According to the calculation of a 5% error in bulk density, the variation of stress during the lifting condition of 1# and the completion condition of the bridge is calculated. A 5% error in bulk density results in a maximum error of ±1.6 MPa for the stress of top plate and an error of ±3.0 MPa for the bottom plate. The influence value of bulk density on the stress of the top and bottom plates of steel box beams is shown in Figures 13 and 14.
4.3.2. Sensitivity Analysis of Elastic Modulus

![Diagram of vertical deflection change of integrated steel box girder caused by bulk density.](image)

**Figure 12.** Vertical deflection change of integrated steel box girder caused by bulk density.

![Diagram of stress error on the top plate of steel box beams.](image)

**Figure 13.** The influence value of bulk density on the stress of the top plate of steel box beams.

![Diagram of stress error on the bottom plate of steel box beams.](image)

**Figure 14.** The influence value of bulk density on the stress of the bottom plate of steel box beams.
4.3.2. Sensitivity Analysis of Elastic Modulus

As is well known, the diversity of steel and the influence of temperature variation could lead to changes in the elastic modulus. Therefore, conducting a sensitivity analysis of the elastic modulus is necessary in order to assess the impact of using different steel types and extreme disasters on the stress and deformation of the steel box bridges. Based on the calculation of an error of 5% in the elastic modulus, the deflection variation during the lifting condition of the 1# span and the completion condition is calculated. Taking an increase of 5% in the elastic modulus as an example, the variation in the mid-span deflection is shown in Table 4. The variation in the mid-span deflection during the lifting condition of the 1# span reaches −4.7% of the mid-span deflection. During the completion condition, the deflection variation in each span is −4.7% to −4.1%. The structural deformation is shown in Figures 15 and 16.

<table>
<thead>
<tr>
<th>Construction Conditions</th>
<th>Lifting the 1# Span</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mid-Span of 1#</td>
<td>Mid-Span of 1#</td>
</tr>
<tr>
<td>Original deflection (mm)</td>
<td>−196.2</td>
<td>−170.0</td>
</tr>
<tr>
<td>Deflection (mm)</td>
<td>−186.9</td>
<td>−162.9</td>
</tr>
<tr>
<td>Rate of change (%)</td>
<td>−4.7%</td>
<td>−4.1%</td>
</tr>
</tbody>
</table>

Figure 15. Vertical deflection variation of the first span steel box girder caused by elastic modulus.

4.3.3. Sensitivity Analysis of Temperature

(1) The effect of overall heating on structural deformation

Taking an overall temperature rise of 10 °C and an overall temperature drop of −10 °C, the longitudinal deformation of the structure under the overall temperature difference is shown in Figure 17. The fixed support is located at 0 m, and the structural deflection remains virtually unchanged under the overall temperature difference.

(2) The influence of local temperature difference on structural deformation

The effect of local temperature difference on structural deformation of steel box beams is set according to the height of the section. For example, a temperature gradient of +10 °C is set, with a linear distribution along the beam height of 10 °C for the top plate and 0 °C for the bottom plate. The deflection changes during the lifting condition of 1# and the completion condition is calculated. Under the action of a 10 °C temperature difference, taking a positive temperature difference as an example, the
mid-span deflection of the lifting condition of 1# can reach 34.0 mm, and the deformation of cantilever end can reach \(-34.0\) mm. The maximum structural deformation under the completion condition can reach 12.7 mm, which occurs in the middle of the side span. The structural deformation diagram for each working condition is shown in Figures 18 and 19.

(3) The influence of local temperature difference on structural stress

The temperature gradient is set in a consistent manner with deflection deformation to study the effect of local temperature on structural stress. Due to the fact that there are no additional constraints on the steel box girder as a statically indeterminate structure during the lifting condition of 1#, the temperature gradient does not have an impact on the corresponding stress under the lifting condition of 1#. Under the action of positive temperature difference in the bridge completion condition, the stress range of the top plate of the structure is \(-10.4~0\) MPa, and the stress range of the bottom plate is 0~18 MPa. Under the action of negative temperature difference, the stress range of the top plate of the structure is 0~10.4 MPa, and the stress range of the bottom plate is \(-18~0\) MPa. The results of stress calculation are shown in Figures 20 and 21.
Figure 18. Deflection error caused by temperature difference between top and bottom plates at 10 °C under 1# condition.

Figure 19. Deflection error caused by temperature difference between top and bottom plates at 10 °C under bridge completion condition.

Figure 20. Structural stress under the effect of +10 °C temperature difference under bridge completion conditions.
Floor stress

Figure 21. Structural stress under the effect of −10 °C temperature difference under bridge completion conditions.

As the construction progresses, the numerical simulation will provide valuable guidance for construction monitoring. Starting from the prefabrication of steel box girders at the factory to the final closure of the entire bridge, the construction monitoring platform will rely on the numerical simulation results throughout the whole construction process. All field-measured stress and displacement data must be compared and analyzed against the results of FEM on the platform, to ensure that the structural safety during construction and the stress and displacement of the bridge after closure are within the design requirements. In particular, the construction monitoring platform will provide real-time construction instructions and guide the installation process, especially for monitoring the stress on the corbel connections, which are the main load-bearing components before the completion of welding.

5. Research on Monitoring Platform

This section will introduce the monitoring platform developed based on construction monitoring and control. During the phased construction of the bridge, the geometric state and force status of each component are constantly changing. Whether the bridge alignment meets the accuracy requirements, whether the structural force and deformation are consistent with expectations, whether the components can be spliced smoothly, whether the designed bridge state can be achieved, etc. These are issues of great concern to all parties involved in the construction. The construction monitoring work is carried out around the above problems, and the development of information and digital technology provides effective auxiliary means for the bridge construction monitoring work.

As shown in Figure 22, the construction of the bridge construction monitoring digital platform is based on the premise of data standardization. The structural response data of the construction process is used as the main chain, connecting monitoring and calculation, monitoring instructions, construction monitoring, error analysis, monitoring and warning, and other work. The platform focuses on solving the problems of complete collection of structural response, rapid data analysis, and timely information release, providing digital technical support for bridge construction and monitoring decision-making. To achieve the above goals, an end-to-end cloud collaborative system architecture based on core concepts such as the Internet of Things, the Internet, distributed microservices, and front-end/back-end separation is an ideal architectural choice.
At the collection end, design independent collection modules that can dynamically interface with different types of hardware devices and achieve data synchronization collection through multi-process mode, as well as the collected monitoring and detection data, will be transmitted to the cloud platform in real time through the network after secure encryption and compression.

In the cloud, the platform is divided into multiple subsystems, and services are constructed with a micro-service architecture to realize a high-performance cloud platform that supports distributed deployment. Bridge construction monitoring involves structural facilities, theoretical prediction, on-site monitoring, construction business, and other types of data, for which a unified database is designed to specify the data standardized format, and the data is stored in series in a structured mode to ensure efficient data query, as well as good scalability.

The bridge construction monitoring digital platform usually includes information perception, data transmission, data governance, data management, business application and integrated display, and other levels. This platform covers the entire process of data perception, aggregation, processing, governance, analysis, display, and service, and supports the use of BIM models for construction process information management and display.

1. Information perception layer: dynamically collect status information during the bridge construction process through sensing devices of IoT, intelligent construction equipment, third-party channels, and other channels.
2. Data transmission layer: the data transmission of the information perception layer is realized by the combination of wireless communication and private network, and the security of the transmission process is guaranteed by the Internet data security transmission technology.
3. Data governance layer: the data uploaded by the data transmission layer is treated, processed, aggregated, desensitized, encrypted, and published. At the same time, the corresponding algorithm is used to calculate the corresponding index value according to the technical indicators set by the user.

Figure 22. Architecture of digital platform for bridge construction monitoring.
4. Data management layer: through standardized management of all data, complete data archiving, query, storage, etc, this provides a reliable distributed data exchange and storage platform for each application subsystem to facilitate the development and application of data.

5. Business application layer: the platform is divided into multiple business systems that can be independently designed, developed, operated, and maintained according to the idea of componentization and servitization. These applications interact and integrate through service calls.

6. Integrated display layer: a data display window for bridge construction, management and quality supervision and other units and personnel through a large screen, PC terminal, mobile terminal, and other interactive channels. This window can highlight the key and related information, and visualize complex information.

6. Conclusions

The engineering background of this paper is a continuous steel box girder of the large cross-sea bridge, with the goal of developing a construction scheme for the overall lifting of large section steel box girder. The problems encountered in monitoring and the main technical means were studied and analyzed. This paper summarizes the monitoring work and digital monitoring system of the large-section steel box girder hoisting at various stages, including pre-construction preparation, box girder manufacturing, installation, and bridge operation and maintenance after installation. It introduces in detail the importance and difficulties of construction control of large section hoisting. Furthermore, the corresponding alignment, stress, and temperature monitoring schemes are formulated by combining theoretical analysis, the finite element model, and digital application. The construction proceeded smoothly and was completed within the designated timeframe. After the erection of the main beam, the linear accuracy meets the requirements, and the implementation of the project has achieved good results. The bridge has achieved a successful opening to traffic with good operating conditions, serving as a valuable reference for other bridges of its kind. The following conclusions are drawn:

(1) The method of the overall lifting of large-segment girders is increasingly common in use. This paper adopts a comprehensive monitoring approach, starting from the prefabrication stage at the steel box girder factory. Taking the first large segment as an example, specific methods for stress and displacement monitoring are described to ensure the structural safety during the construction process.

(2) The influence of material parameters such as weight, elastic modulus, and temperature on the stress and displacement of steel box girders is analyzed. The variations in stress on top and bottom plates and vertical displacement with changes in these parameters are provided as references for the project.

(3) Based on this project, a construction monitoring platform has been developed, which mainly realizes on-site data collection to the cloud and real-time remote monitoring of the steel box girder lifting process. This lays the foundation for establishing a digital monitoring system for the entire lifecycle of the bridge.

7. Outlook

Due to the limitations of individual ability and objective conditions, there are still some problems for further study:

(1) The consideration of construction influencing factors is not sufficient. The influencing factors, such as the settlement of the tire frame and the contraction of the assembled weld on the linear shape, has not been considered. The influence of transverse local temperature difference on the structure of box girder needs to be evaluated.

(2) Digital application needs to be improved. At present, digital technology is mainly used for data acquisition and monitoring of the hoisting process, but it is not intelligent enough in data processing and error adjustment. A digital monitoring system for the whole life cycle of bridges should be developed as a matter of urgency. The
development of digital technology and artificial intelligence technology will enable bridge construction monitoring to develop in the direction of digitalization, intelligence, real-time warning, whole process monitoring, and safety guarantee, so as to provide a more comprehensive and detailed guarantee for the safety and quality of bridge construction.

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