Research on Key Technology of Steel Box Girder Construction Based on Measured Temperature Mode

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Abstract: The temperature effect has a great impact on the reasonable completion state of the steel box girder. The relevant research has an important role in promoting the design, construction and operation and maintenance of the steel box girder. Firstly, the effects of uniform temperature difference and gradient temperature difference are analyzed, and three gradient temperature difference modes are compared; Based on the construction monitoring project of a continuous steel box girder, the longitudinal bridge displacement of the support under different uniform temperature difference conditions is calculated. The results show that the overall displacement and relative displacement are considered in the pre deflection of the support; The beam end angle under three different gradient temperature difference modes is compared, and the calculation formula of the top and bottom plate cutting caused by the beam end angle is proposed. This paper systematically studies the influence of uniform temperature difference and gradient temperature difference on the positioning of steel box girder support and the closure of weld seam, and puts forward countermeasures, which will provide some theory and engineering experience for similar projects in the future.

Keywords: Uniform Temperature; Gradient Temperature; Bearing Pre Deflection; Beam End Angle; Top and Bottom Plate Cutting

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1 Introduction

In view of its advantages of good bending resistance, torsion resistance and convenient construction, steel box girder has been widely used in crossing structures. For large-span statically indeterminate structures, uniform temperature difference and gradient temperature difference are one of the factors that affect the secondary internal force and vertical deflection of the structure [1]. In 2001, during the construction monitoring of Nanjing Second Yangtze River Bridge, it was found that the temperature difference between the top and bottom plates caused the vertical displacement of the main beam, with the maximum height difference of 11.04cm and the longitudinal expansion and contraction of 0.4cm [2]; In 2006, based on the temperature monitoring of Zhanjiang Ocean Bridge, it was found that the vertical temperature difference distribution pattern of the web along the beam height can be approximately expressed by an exponential curve [3]; In 2009, based on the monitoring of Hangzhou Jiangdong Bridge, it was found that the sunshine gradient temperature difference of steel box girder was

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significantly different from the gradient temperature difference specified in the design code for highway bridges and culverts in China, and the relevant parameters need to be corrected before they can be used in the project [4]. As for the influence of uniform temperature difference and gradient temperature difference of steel box girder structure under solar radiation, many experts and scholars have carried out a lot of research. However, there are relatively few measured data on uniform temperature difference and gradient temperature difference in China. The gradient temperature difference effect of current highway bridge and culvert specifications basically refers to American AASHTO specifications, and is only limited to concrete box girder and steel structure with concrete bridge deck, for orthotropic steel bridge deck and steel box girder, there are no relevant provisions [5-9]. Firstly, the article compares the influence of the overall temperature rise and fall and the local gradient temperature difference with the domestic specifications and the British BS 5400 specifications. Based on a continuous steel box girder construction monitoring project, the finite element model is used to analyze the influence of the uniform temperature difference and the gradient temperature difference on the hoisting and positioning construction of the steel box girder, and the influence of the support pre deflection and the beam end angle is analyzed in detail. Finally, the formula of the top and bottom plate matching is derived, This paper analyzes the temperature monitoring, the uniform temperature difference, the gradient temperature difference and the calculation of the longitudinal displacement and vertical rotation angle of the structure, which provides some theory and engineering experience for similar projects in the future.

2 Project Overview

A continuous steel box girder bridge, the total length of the bridge is (80.0 + 120.0 + 110.0 + 80.5) M = 390.5m, the transverse arrangement of the bridge deck is: 0.5m (guardrail) + 8.0m (motorway) + 0.5m (isolation guardrail) + 8.0m (motorway) + 0.5m (guardrail) = 17.5m, the width of the box girder bottom plate is (3.85 + 3.8 + 3.85) M = 11.5m, the beam height fulcrum is 6.0m, and the span is 3.0m. The steel box girder is composed of the deck top plate, bottom plate, side longitudinal web plate, middle longitudinal web plate and transverse diaphragm. The top plate is an orthotropic plate with a thickness of 16-28mm and the bottom plate is 24-45mm. The transverse diaphragm mainly provides the transverse rigidity of the bridge to prevent distortion and deformation, and provides support for the orthotropic plate.

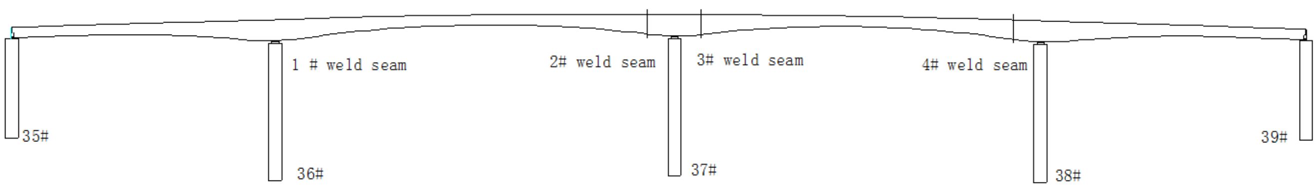


Figure 1 General arrangement of continuous steel box girder bridge

3 Analysis of Temperature Change Mode

As the main influence factor of deformation and secondary stress of steel box girder, the influence of temperature can be divided into uniform temperature difference and gradient temperature difference. The former refers to the change of long-term temperature, resulting in basically uniform elongation and shortening of the structure; the latter is that the sunshine temperature difference forms an uneven temperature difference field in the section, and each part of the box girder generates uneven expansion deformation due to the uneven temperature difference, that is, vertical displacement [10-12]. Therefore, in the construction control of long-span continuous steel box girder, it is not only necessary to monitor the long-term and short-term temperature changes of the box girder, but also to understand the temperature distribution of the box girder section, so as to control the strain test and elevation test deviation caused by the temperature.

3.1 Temperature Monitoring Method

In order to study the temperature distribution and change law of the steel box girder structure and provide environmental correction parameters for the pre deflection arrangement of the support and the welding time of the weld, three section positions are set in the longitudinal direction of the bridge, which are respectively selected at L / 4 of the single span, that is, to ensure that the height of each section is consistent, and 12 sensors are arranged in the transverse direction of each section, totaling 36 sensors. The cross-sectional layout is shown in the following figure.

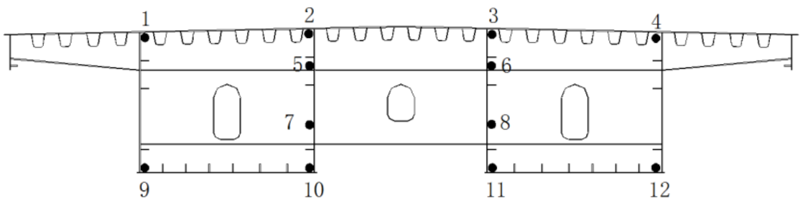


Figure 2 Layout of main beam temperature monitoring points

3.2 Uniform Temperature Difference

For the steel box structure, the value shall be taken according to the code for design of highway steel structure bridges (JTG D64-2015) and the general code for design of highway bridges and culverts (JTG D60-2015), and the local maximum and minimum temperature shall be taken as the system temperature difference. The calculation formula is as follows:

The temperature is between 20 ℃ and 45 ℃, and the temperature of steel bridge with steel deck is:

$$T_e = 38.0 + \frac{T_t - 20.0}{2.0}$$

The temperature is between - 2 ℃ and - 50 ℃, and the temperature of steel bridge deck is:

$$T_e = \text{-}1.48 + \frac{T_t}{0.91}$$

Where: is the standard value of effective temperature of structure (℃);

It is the highest daily average temperature or the lowest daily average temperature (℃) over the years.

According to the statistical data of Shanghai Meteorological Bureau, the local highest temperature in the month is 38.0 ℃, and the lowest temperature is - 2.0 ℃. Therefore, according to the above formula, the maximum temperature of the top plate of the steel box girder is 47 ℃, and the minimum temperature is -3.68 ℃.

3.3 Gradient Temperature Difference

The temperature change during the typical period of box girder erection, i.e. from June 15 to June 17, 2020, is selected for research. See Figure 3 for the temperature change of 4 measuring points 2#, 5#, 7#, and 10#, which are distributed along the beam height direction in the web of the main beam section.

According to Figure 3, it can be found that the maximum temperature of the four measuring points is 13:00 and the minimum temperature is 02:00. In order to compare the temperature difference effects of the highest temperature and the lowest temperature, the node temperature in the typical time period is selected for comparative analysis. The deformation curve is shown in Figure 4.

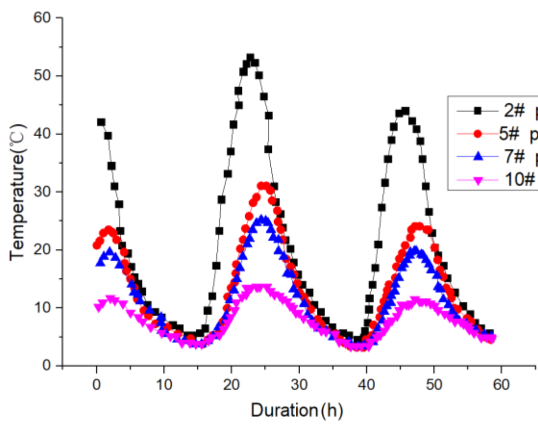


Figure 3 Time history curve of temperature change along section of middle web of steel box girder

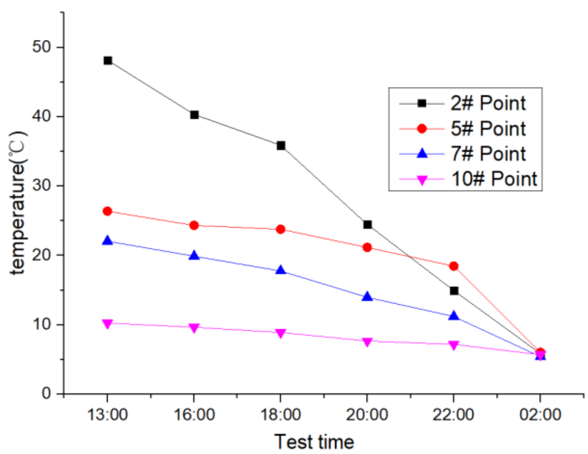


Figure 4 Temperature change curve of typical measuring points of middle web of steel box girder

According to the temperature gradient load of the maximum temperature difference distribution as the control temperature load, at 18:00 on June 16, the fitted temperature gradient curve was compared with the Chinese and British specifications. The results show that the measured gradient temperature difference curve is closer to the British specifications. The specific comparison is shown in the following figure.

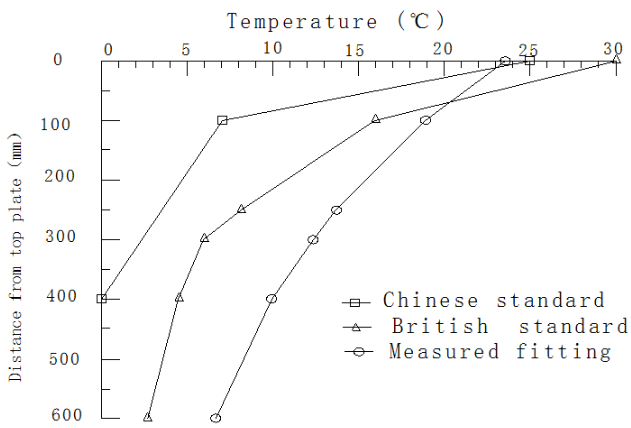


Figure 5 Comparison of vertical temperature gradient modes

4 Finite Element Model and Working Condition Analysis

4.1 Finite Element Model

The general finite element software is used for modeling. There are 179 nodes and 178 elements in the whole bridge. The sections used are all established according to the actual section shape and size. The boundary conditions are consistent with the actual construction conditions. The whole bridge model and the typical section model are shown in Figure 6.

Figure 6 Finite element model for structural calculation

For the key construction processes such as segment lifting, mid span closure and support removal, elastic connection is used to simulate the connection between the support and the mass, and the translational direction of the support is simulated through the constraint degree of freedom. Two bearings are set on a single pier, and there are 10 bearings in total for the whole bridge. One fixed bearing is set on 37 # pier, and the other piers are set with longitudinal movable bearings, one of which limits the freedom in the transverse direction of the bridge.

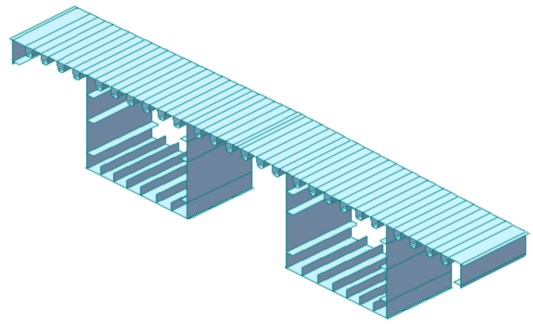


Figure 7 Beam element segment model

4.2 Working Condition Analysis

4.2.1 Uniform Temperature Difference

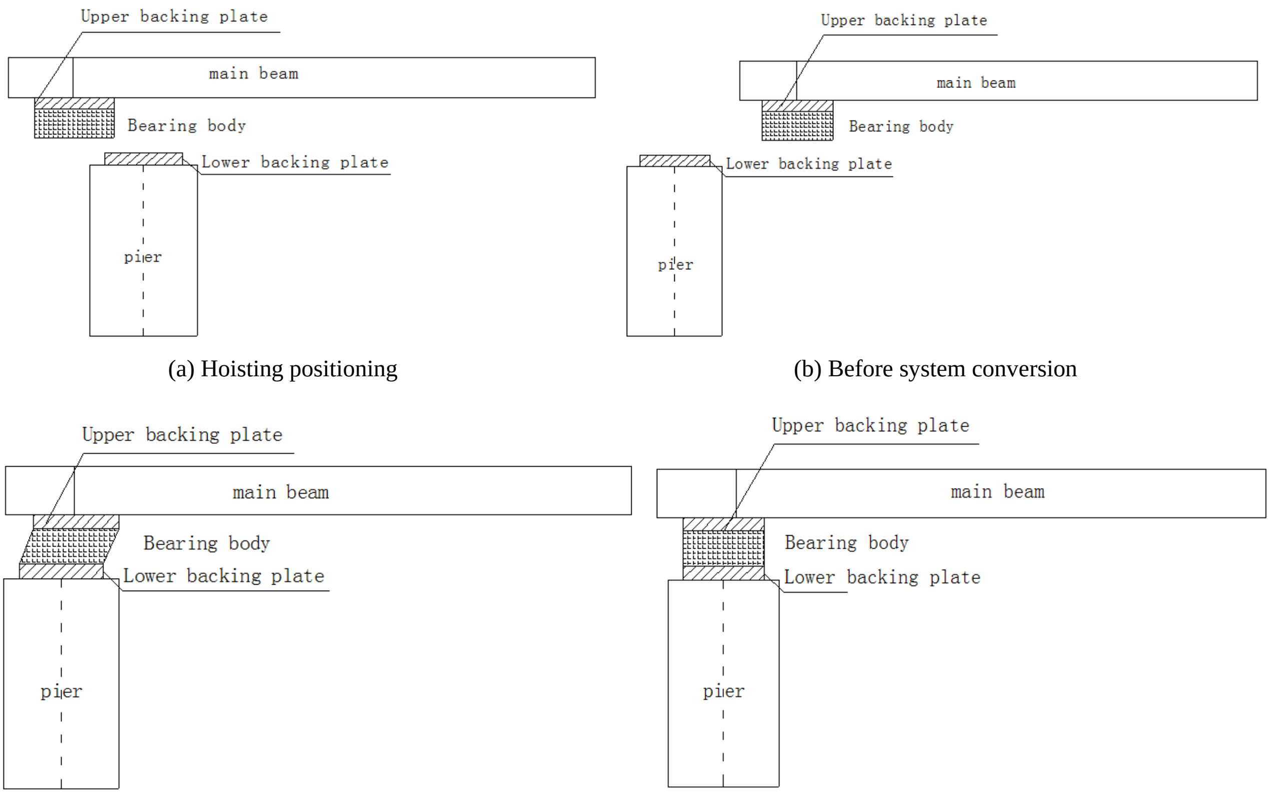
For the continuous steel box girder constructed by segmental hoisting, due to the existence of structural dead weight, temperature and construction load, it is inevitable that the length of the top plate and bottom plate of the main beam will change. Considering the factors such as the factory manufacturing deviation, installation and positioning deviation and welding shrinkage deformation of the beam length, the bridge support will inevitably undergo longitudinal deformation due to eccentric stress, which will affect the normal service performance of the support. Therefore, it is necessary to set the bearing offset between the bearing pad on the beam bottom plate and the bearing design center line.

During the construction process, the box girder sections are first suspended on the temporary support in the simple support state. After the completion of the welding seam closure, other sections are installed in turn until the whole beam is dropped and the system conversion is completed. According to the system transformation during the construction, the bearing displacement during the construction mainly includes the overall displacement and the relative displacement (Figure 8 and Figure 9):

(1) The displacement before the transformation of the bearing system is the overall displacement of the bearing in the longitudinal direction of the bridge. The beam body is positioned on the temporary support, and the support body is fixed on the bottom plate of the beam body. Under the action of structural dead weight, temporary load and temperature load, the beam body will undergo longitudinal bridge direction deformation, and the base

plate on the support will generate longitudinal bridge direction displacement with the deformation of the bottom plate of the beam body;

(2) The displacement after the transformation of the bearing system, i.e. the relative deformation of the bearing. The bearing is installed on the pier, and the longitudinal bridge deformation of the beam under the load will drive the relative displacement between the upper and lower cover plates of the bearing.



(a) Hoisting positioning (b) Before system conversion

(c) After system conversion (d) Design basis value status

Figure 8 Schematic diagram of bearing displacement during construction

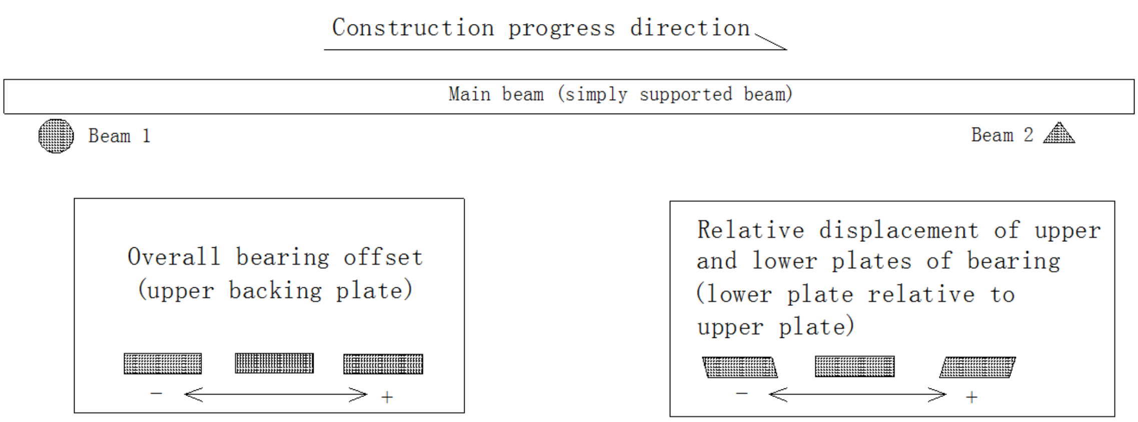
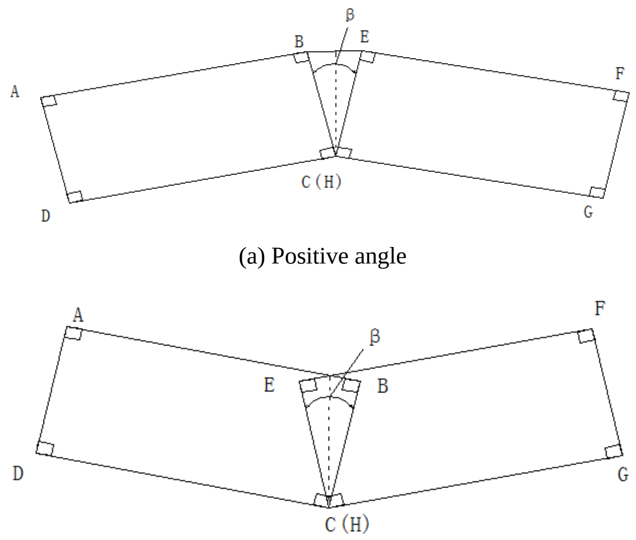


Figure 9 Provisions on sign of overall and relative displacement of bearing

4.2.2 Analysis of Local Temperature Difference

During the installation and erection of steel box girder sections, the angle between the beam ends of the erected sections and the sections to be erected will inevitably appear at the welding seam (Figure 10). Whether the angle between the beam ends of the adjacent sections is consistent is the key to the smooth closure of the steel box girder.



(a) Positive angle

(b) Negative included angle

Figure 10 Included angle of beam end

When the steel box girder is manufactured in the factory, if the section closure is not cut, the included angle of the top plate center line at the section welding closure can be determined according to the installation line of the steel box girder section at the construction stage, and the included angle at the beam end can be calculated β. The installation alignment and section size of ABCD and efgh of beam section are known. LCD, LCE and LDE are the dimensions of CD section, CE section and de section respectively. According to the geometric deformation conditions, the included angle of beam end β The calculation is as follows:

$$\beta = \arccos(\frac{L_{CD}^2 + L_{CE}^2 - L_{DE}^2}{2L_{CD}L_{CE}})$$

If there is an included angle between the beam ends of adjacent segments β, It will inevitably cause difficulties in closing the top and bottom plates. In order to reduce the difficulty of closure, the beam section shall be matched and closed when the temperature difference between the top and bottom plates is small (≤ 2℃). However, the actual construction process cannot ensure that all construction processes can meet the requirements of closure temperature difference. Therefore, research and treatment shall be conducted according to the actual temperature distribution.

According to the fitting temperature gradient curve shown in Figure 5, select the representative temperature time point, adopt the three fold line mode, and select a series of temperature modes to simulate the temperature difference according to the measured temperature difference mode (Figure 4). See Table 1 for the specific data.

Table 1 Temperature parameters based on measured series of temperature gradient modes

Gradient temperature difference / Distance from top plate	M0	M1	M2	M3	M4	M5	M6	M7	M8
0mm	Not considered	23.5	21.9	18.6	15.1	12.7	6.0	4.3	2.0
100mm		19.0	17.7	16.7	10.2	9.1	4.4	3.6	1.9
300mm		12.5	11.7	13.4	4.7	3.4	2.4	2.4	1.7
600mm		6.7	6.2	9.6	1.5	1.2	0.9	1.4	1.5

5 Analysis of Calculation Results

5.1 Influence of Uniform Temperature Difference on Structure

The influence of uniform temperature difference on the structural deformation of steel box girder is mainly reflected in the pre deflection setting of the longitudinal bridge direction of the support. The bearing pre deflection value includes not only the temperature effect, but also the pre deflection value caused by the load effect [13, 14]. In order to study the influence of uniform temperature difference on bearing pre deflection, the longitudinal bridge displacement of bearing caused by non temperature load (such as structural dead weight, temporary load, etc.) is calculated first, and then the change of bearing displacement caused by temperature change is studied. See Table 2 for the longitudinal bridge displacement and pre deflection of the bearing under the action of non temperature load in the construction stage.

Table 2 Bearing displacement and pre deflection under non temperature load

Parameter	35# Pier	36# Pier	37# Pier	38# Pier	39# Pier
Bearing displacement	-13.3	-11.8	0.0	13.8	11.9
Bearing pre deflection	13.3	11.8	0.0	-13.8	-11.9

The influence of the uniform temperature difference on the longitudinal bridge displacement of the bearing includes the overall displacement and the relative displacement. Since the temperature at the bridge site is in dynamic change, it is necessary to consider the bearing displacement under different temperature differences to provide technical data for bearing positioning and steel box girder hoisting. Taking the temperature range of 0.0℃ ~ 40.0℃ and taking 5℃ as interval, the overall displacement, relative displacement and total displacement of steel box girder support under different uniform temperature difference are calculated based on the measured information of local temperature. See Table 2 for the specific results.

Table 3 Bearing displacement under the influence of different temperatures

Pier No.	**displacement**	**temperature (℃)**								
		0.0	**5.0**	**10.0**	**15.0**	**20.0**	**25.0**	**30.0**	**35.0**	**40.0**
35# Pier	bodily movement	50.2	38.1	26.2	14.2	0.0	-9.7	-21.7	-33.6	-45.6
	Relative displacement	-2.2	-2.2	-2.2	-2.2	0.0	-2.2	-2.2	-2.2	-2.2
	Total displacement	48.0	35.9	23.9	12.0	0.0	-12.0	-23.9	-35.9	-47.8
36# Pier	bodily movement	30.0	22.8	15.6	8.4	0.0	-6.0	-13.2	-20.4	-27.6
	Relative displacement	-1.2	-1.2	-1.2	-1.2	0.0	-1.2	-1.2	-1.2	-1.2
	Total displacement	28.8	21.6	14.4	7.2	0.0	-7.2	-14.4	-21.6	-28.8
37# Pier	bodily movement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Relative displacement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total displacement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38# Pier	bodily movement	-30.1	-23.5	-16.9	-10.3	0.0	2.9	9.5	16.1	22.7
	Relative displacement	3.7	3.7	3.7	3.7	0.0	3.7	3.7	3.7	3.7
	Total displacement	-26.4	-19.8	-13.2	-6.6	0.0	6.6	13.2	19.8	26.4
39# Pier	bodily movement	-43.6	-36.2	-24.8	-13.4	0.0	9.3	20.7	32.1	43.5
	Relative displacement	2.1	2.1	2.1	2.1	0.0	2.1	2.1	2.1	2.1
	Total displacement	-41.5	-34.2	-22.8	-11.4	0.0	11.4	22.8	34.2	45.6

In Table 3, the support of 37 # pier is dropped after the section 3 # is hoisted and welded. The temporary fixed support on the pier top is not removed, so there is no overall displacement of the support. And one of the supports of 37 # pier is a fixed support, so there is no relative displacement of the support of 37 # pier. The data in the table shows that, relative to 37 # pier, the supports on both sides generate longitudinal bridge displacement relative to 37 # pier, and the farther the distance, the greater the overall displacement, that is, before the beam is dropped, the overall displacement of the supports Δ LT and uniform temperature difference meet Δ Lt= αΔ TL relationship (where, α Is the linear expansion coefficient of steel, Δ T is the uniform temperature difference value, l is the segment length); After the beam is dropped, the relative displacement of the support is relatively small and can be ignored during the construction.

5.2 Analysis of Beam End Rotation Angle Under Measured Gradient Temperature Difference Mode

According to the included angle of beam end β According to the calculation formula, the beam end included angles of welded ends 1, 2 and 3 under different temperature gradient modes can be obtained. See Table 4 for details.

Table 4 Included angle of beam end at welding end under temperature gradient mode

Gradient temperature difference / **Closure port**	**M0**	**M1**	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**
Port1	0.000	0.009	0.006	0.019	0.157	0.186	0.285	0.372	0.390	0.058
Port2	0.000	-0.223	-0.228	-0.209	-0.095	-0.070	-0.001	0.046	0.041	0.027
Port3	0.000	-0.244	-0.236	-0.219	-0.114	-0.087	-0.009	0.053	0.052	0.040

According to the data in the above table, the following conclusions can be drawn:

(1) During the closure welding of port 1, no matter how large the gradient temperature difference is, the included angle at the beam end is inevitable and the value is large, that is, corresponding adjustment measures shall be taken to adjust the included angle at the beam end at this construction stage;

(2) During the closure welding of port 2 and port 3, under the action of M1-M5 gradient temperature

difference, the included angle at the beam end is negative, and the bottom plate needs to be corrected; Under the gradient temperature difference of M6-M8, the included angle is positive, and the top plate needs to be corrected. Therefore, for the closure construction of port 2, the closure welding can be carried out under the appropriate gradient temperature difference (M5-M6).

The included angle of the beam end under different gradient temperature difference will bring different degrees of overlap of the top plate or the bottom plate of the box girder. In order to smoothly close, the top plate and the bottom plate of the steel box girder need to be cut and corrected to ensure the smooth connection of the segments. The correction length is calculated as follows:

$$\Delta L = h \cdot tan(\beta)$$

In the above formula, Δ L is the correction amount of top plate (bottom plate);

H is the height of steel box girder.

During the installation and construction of box girder sections, due to the influence of manufacturing error, construction error, temperature and other factors, the included angle of the beam end of the box girder at the site section is inevitable, and even affects the smooth connection of the sections. According to the site conditions, measures such as adjusting the welding seam, adjusting the height of the support, and adjusting the weight can be selected for adjustment [15-17].

6 Result

This paper systematically studies the influence of uniform temperature difference and gradient temperature difference on the hoisting and closure construction of steel box girder, and the main conclusions are as follows:

(1) The measured gradient temperature difference of steel box girder is closer to the British standard BS5400;

(2) When the temperature difference is uniform, the steel box girder will generate longitudinal bridge displacement. When the longitudinal displacement of the main beam under non temperature action is considered, the overall longitudinal bridge displacement and relative displacement shall be considered for the bearing pre deflection;

(3) The beam end angle is different under different gradient temperature difference modes, and appropriate closure welding time, appropriate adjustment measures or appropriate cutting amount shall be selected according to the beam end angle.

The above research results show that the uniform temperature difference and the gradient temperature difference have a great impact on the longitudinal and vertical displacement of the steel box girder. For the uniform temperature difference, it can be offset by the pre deflection of the support. The gradient temperature difference can be constructed under the relatively stable temperature state, or adjusted by adjusting the weld, the support height and the weight according to the size of the corner and the height of the box girder.

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