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Research on Assembly Time for Steel Girder

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Abstract: To provide technical basis for assembly steel girder in incremental launching method, aimed at the problem of assembling steel girder leaded erection line change which is influenced by temperature variation. According to the vertical temperature variation of steel girder measures in situation in this paper, temperature gradient model was fitted, and the influence of angle for assembly steel girder end under different temperature gradient model was investigated. The results show that angle of assembly steel girder end caused by temperature gradient of top and bottom plane was remarkable. Different assembly temperature scope for top and bottom plane of steel girder was suitable to different segments.

1. Research Background

Steel box girders are suitable for large-span bridges due to their excellent torsional and bending resistance. The steel box girder top pushing construction method has been widely used in the world. In fact, the complex stress characteristics, steel girder welding, temperature difference changes, and other factors have increased the difficulty of linear control during its construction process.

The thermal conductivity of steel box girders is good. However, because they are exposed to atmospheric conditions that they are not only affected by seasonal and annual temperature changes, but also by local temperature differences caused by sunlight, therefore, the nonlinear temperature difference in the cross-section of the girder is significantly affected. Nonlinear temperature has a significant impact on the force and linearity of girders. Due to the complexity of this temperature effect, semi theoretical and semi empirical calculation methods are often used [1-3].

Hao Chao et al.[4] studied the influence of nonlinear temperature on the construction stage of large-span steel box girder cable-stayed bridges, and pointed out that the influence of temperature on the installation of steel box girders should be considered, and the elevation of girder installation should be adjusted based on the measured temperature difference on site; Deng Xiaowei et al.[5]

discussed the temperature difference effect and temperature parameter sensitivity of large-span steel box girder cable-stayed bridges from four aspects: girder temperature difference, main tower temperature difference, cable girder tower temperature difference, and system temperature difference; Pan Wenli et al.[6] showed the effect of transverse and vertical temperature differences on steel box girder cable-stayed bridges, and the research results showed that they have an impact on girder displacement and cable tension; Ding Youliang et al. [7] believed that the cross-sectional temperature of steel box girders has symmetry, and there is a positive temperature difference gradient between the top and bottom plates of the steel box girders; Sun Jun et al.[8-12] figured out that there is a significant difference in the transverse temperature of the top plate of steel box girders; Wang Gaoxin et al.[13-14] discussed that the temperature of flat steel box girders can be described by the weighted sum of normal distribution functions to describe their probability density distribution; Qian Kun et al.[15] pointed out that the temperature gradient values specified by various countries are varied from the measured temperature gradient values on site, and a more practical temperature gradient model should be developed. Guo Qiwu et al. [16-20] found that the overall temperature rise and fall of the structure has a relatively small impact on the vertical displacement of the structure, but has a great impact on its longitudinal displacement; When the temperature of the tire frame is inconsistent with the design temperature, the nonlinear temperature difference formed by the local temperature difference of the girder will have a great influence on the vertical displacement of the girder.

2. Section of Temperature Difference Mode

The above research results indicate that the vertical nonlinear temperature difference of the girder has a significant impact on the girder shape, and the research results are mostly concentrated in the cantilever assembly or bridge completion stage and have no reports on the influence of the top push construction steel box girder assembly shape. This article is based on the measured temperature difference data on site to study the influence of temperature difference on the assembly of steel girders, and focus the timing of steel box girder assembly.

A certain bridge is a 145 m + 240 m + 145 m low tower cable-stayed bridge. The main girder is a single box three chamber steel box girder, with a height of 4.80 m and a full width of 28.50 m. The steel box girder has a total length of 530 m and is divided into 56 sections. The standard section length is 9.6 m, and the longest girder section length is 13m. The main girder is constructed by the top pushing method, and the top pushing of the girder body involves construction in both summer and winter seasons.

In order to study the influence of temperature difference during the assembly process of steel girders, this study uses spatial girder elements for analysis. Using horizontal partitions, segment separation lines, etc. to divide units, and establish cross-sectional dimensions based on the actual cross-sectional dimensions of the structure. In the analysis, only the vertical temperature difference of the girder was considered, without considering the transverse temperature difference effect and negative temperature difference effect.

To study the effect of temperature changes on steel box girders, a typical section was taken as the temperature test section, and 30 temperature measurement points were set up at this section, as shown in Figure 1.

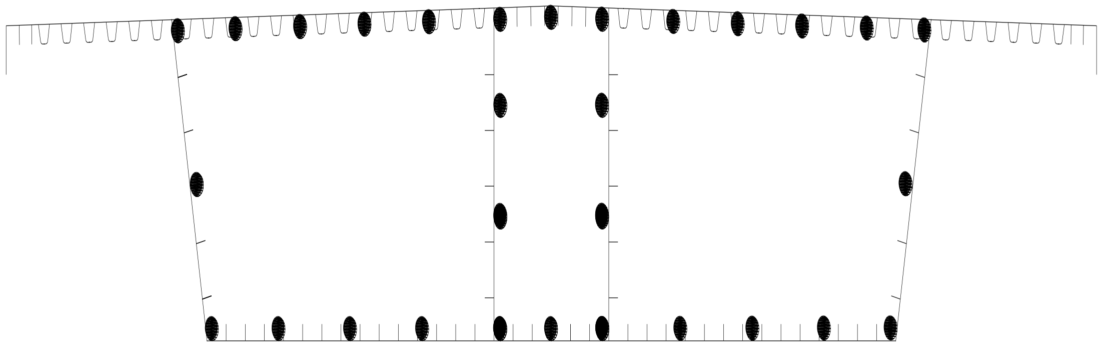

Fig.1 Schematic of Temperature Measuring Points for Typical Cross-section

Select a typical time period in summer for research on temperature changes based on on-site measured temperature data. Figure 2 shows the temperature changes of the web plate in the box girder measured during a certain period in mid-July.

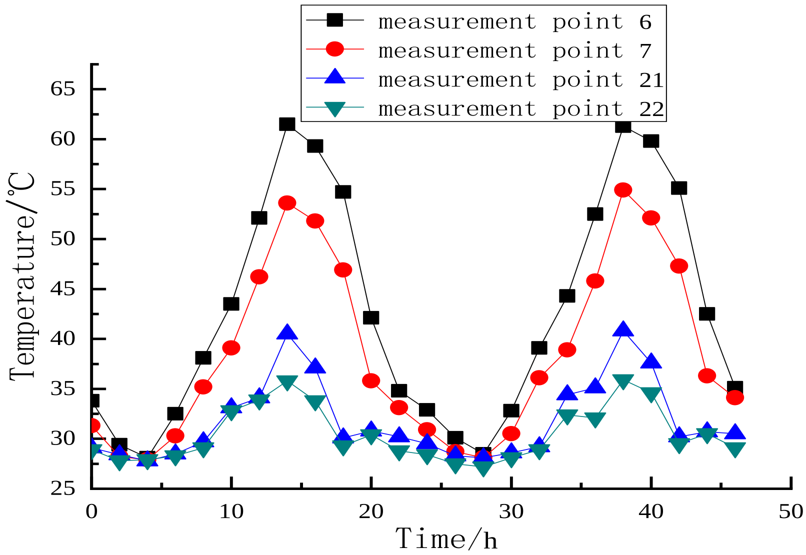

Fig. 2 Vary Curve of Temperature for Steel Girder Internal-web Along Sections

According to the temperature at the bridge site, a formula can be gotten through taking the temperature changes within 48 hours in mid-July and fitting them every 2 hours as a time node.

$$T_y = T_0 e^{-ay} \qquad (1)$$

In the formula (1), T_y is the temperature difference at point y from the top plate of the box girder; T_0 represents the maximum temperature difference along the height direction of the box girder: a shows an exponential parameter; y means the distance from the measuring point to the top plate of the box girder.

As shown in Figure 3, when taking the temperature load with the maximum temperature difference as the temperature control load, fitting the measured temperature data and comparing it with the Chinese standard[21] and the British standard[22]. According to the analysis in Figure 3, the fitted temperature curve is relatively close to the British standard.

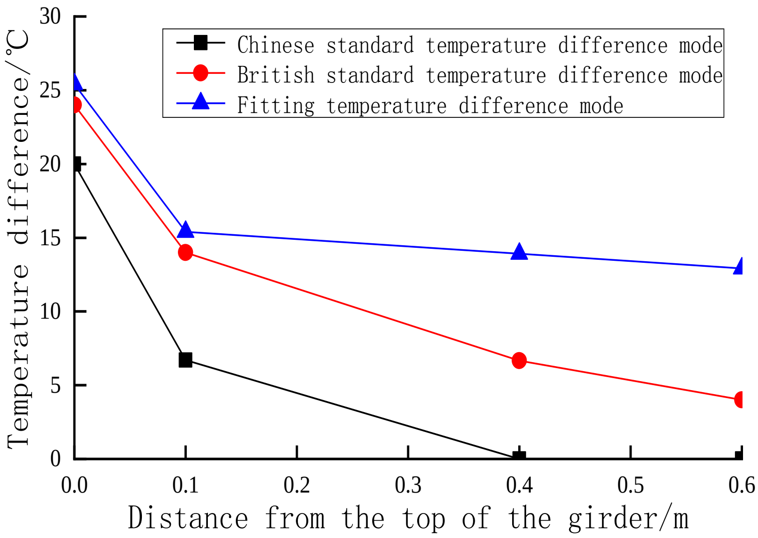

Fig. 3 Temperature Modes Comparison Among Chinese and British Specifications and Presented Modes

3. Analysis of Girder End Angle Based on Field Measured Temperature Difference Mode

The assembly of steel box girders on the frame is achieved by controlling the angle between the girder ends β_i (as shown in Figure 4), which essentially ensures the achievement of unstressed curvature of the girder body. The installation elevation of the girder end to be assembled can be determined using the idea of transfer matrix, and the key is to determine the angle between the girder ends.

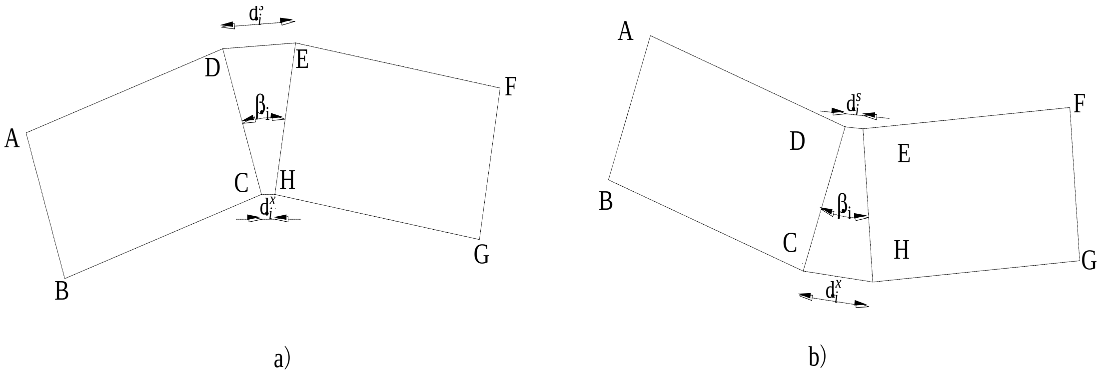

Fig. 4 Schematic of Angle for Girder End

If the manufacturing line and cross-sectional dimensions of girder segment ABCD and girder segment EFGH are known, the β_i expression for the angle between girder segments (assembly angle) can be obtained from the geometric knowledge as

$$\beta_i = arccos\frac{l_{CD}^2+l_{CE}^2-l_{DE}^2}{2l_{CD}l_{CE}} \tag{1}$$

The width difference of the weld seam on the top and bottom plates of the box girder is

$$\Delta d_i = d_i^s - d_i^x = tan\,\beta_i \cdot h_i \tag{2}$$

Table 1 below demonstrates the connections of weld width for top-bottom plane and girder height.

Tab. 1 Relationship of Between Weld Width for Top-bottom Plane and Girder Height

β_i / °	Girder height h_i /mm						
	2000	2500	3000	3500	4000	4500	5000
0.02	0.70	0.87	1.05	1.22	1.40	1.57	1.75
0.04	1.40	1.75	2.09	2.44	2.79	3.14	3.49
0.06	2.09	2.62	3.14	3.67	4.19	4.71	5.24
0.08	2.79	3.49	4.19	4.89	5.58	6.28	6.98
0.10	3.49	4.36	5.24	6.11	6.98	7.85	8.73
0.12	4.19	5.24	6.28	7.33	8.38	9.42	10.47

The angle between the girder ends can be achieved through the width difference of the weld seam on the top and bottom of the box girder to ensure a smooth transition between the girder bodies, During the assembly process of the girder, factors such as manufacturing errors, installation errors. and temperature will affect the angle between the girder segments. To eliminate the above effects, measures such as adjusting the elevation of the jack, the width between welds, or the weight can be taken.

When the temperature difference between the top and bottom of the box girder is small, girder assembly is generally carried out at night. However, due to the actual production situation. girder assembly cannot meet this condition, so analysis should be conducted based on the actual situation of the site. According to the temperature gradient fitting curve based on field measurements shown in Figure3, representative time temperature gradients are selected to analyze the deformation of the girder. Select the temperature at typical representative moments and analyze it using a three-line model in accordance with British regulations. Table 2 shows the temperature parameters based on the measured temperature difference mode on the site.

Tab. 2 Temperature Parameters Based on Practical Temperature Modes

Temperature difference mode	Distance from top plate/mm			
	0	100	300	600
M-1	25.7	15.6	12.8	6.2
M-2	18.2	16.0	13.1	7.9
M-3	11.7	7.1	2.6	1.6
M-4	6.0	3.6	1.4	0.3
M-5	2.6	1.6	1.5	1.2

According to β_i=arctan$\Delta l_i/h_i$, calculate the angle between the girders caused by the temperature difference under different temperature gradient modes. $\beta_i$is the angle between the girder segments caused by the temperature difference and Δl_i represents the longitudinal deformation of the top plate or the bottom plate. The calculation results of the girder end angle under different temperature difference modes are shown in Table 3. And figure 5 shows a schematic diagram of the angle between the girder ends under different temperature difference modes. The angle between the girder ends exists regardless of the temperature difference mode through further analysis, besides, some girder end angles have larger values. Therefore. certain measures need to be taken to limit the angle between the girder ends when assembling the girder.

Tab. 3 Angle of Girder End under Temperature Variation Modes

Temperature difference mode		M-1	M-2	M-3	M-4	M-5
Angle between girder/ °	SB6 port	-0.0281	-0.0230	-0.0126	-0.0064	-0.0028
	SB7 port	0.0503	0.0410	0.0221	0.0113	0.0050
	SB8 port	0.1288	0.1051	0.0568	0.0290	0.0129
	SB9 port	0.2072	0.1691	0.0915	0.0468	0.0207
	SB10 port	0.2851	0.2327	0.1259	0.0644	0.0285
	SB11 port	0.3625	0.2960	0.1602	0.0819	0.0362

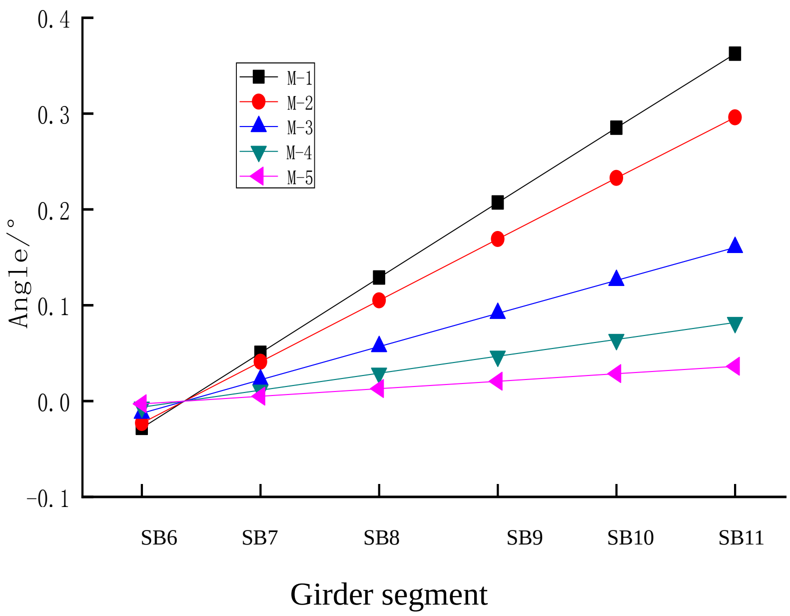

Fig. 5 Schematic Angle of Girder End Under Temperature Variation Modes

4. Determination of the Optimal Assembly Timing

In actual production, the influence of temperature on girder assembly can be eliminated through methods such as jack elevation, weld width, and weight. According to the temperature difference, choose the appropriate assembly time for the angle at the end of the girder body, so that the temperature difference has the least impact on the angle at the end of the girder body, and can even be ignored. This is the best time for girder assembly. Related studies have shown that if the influence of temperature gradient is not considered, the angle between the girder ends is a positive angle under other actions: If temperature effect is considered, the angle between the girder ends is negative.

Based on real-time on-site temperature guidance, it is difficult to determine the timing of girder assembly. It is assumed that the change in temperature difference is equivalent to the change in temperature difference between the top and bottom of the box girder. The typical temperature difference between the top and bottom of the box girder in winter and summer is selected to determine the timing of girder assembly, The time history of temperature difference between the top and bottom of the box girder in mid- July and mid-December in 2021 is shown in Figure 6. It can be seen that the temperature difference between the top and bottom of the girder body in winter and summer is basically the same.

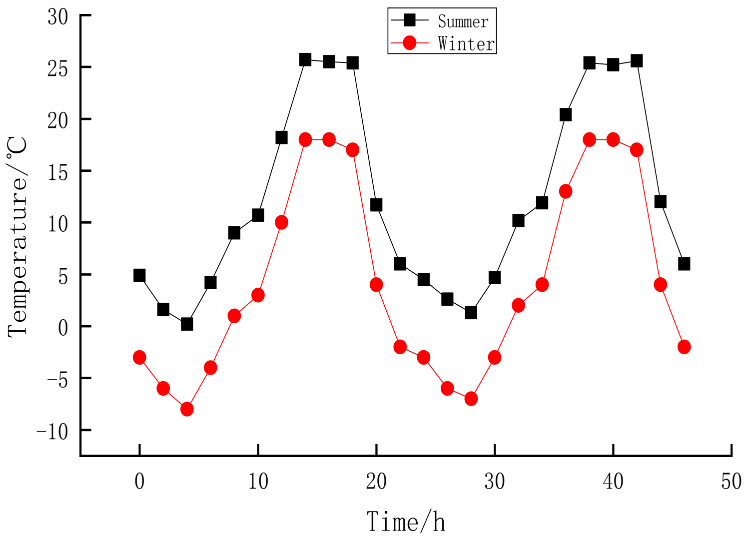

Fig. 6 Temperature Variation of Top-bottom Plane in Typical Climates of Winter-Summer

The girder body of this bridge is assembled on the assembly platform. When the assembled girder body meets the assembly accuracy, temporary components can be used to fix it at the top, bottom, and web plates of the girder body, control the width of the weld seam between the girders, form the assembly line. and then weld it to form the connection between the two girders. The matching components and the assembled girder body are temporarily consolidated using code plates. and the weld width is generally controlled between8-12mm. If the temperature difference is too large, the angle between the ends of the girder is too large. And the relative deformation between the girders is too large, it may not meet the above limitations. Therefore, it is necessary to control the relative deformation between the girders at around 10 mm, and the corresponding maximum rotation angle at the end of the girder is 0.1194 °. Under the effect of temperature difference, the angle between the girders must be controlled within a secondary range, otherwise it will affect the assembly operation of the girders.

Tab.4 Optimal Assembly Times for Different Girder

Girder body port	The optimal assembly timing and temperature range for the girder body	The best assembly time perid	
		Mid-July	Mid-December
SB6 port	0℃~10℃	0:00~9:30 20:00~24:00	Whole day
SB7 port	0℃~10℃	0:00~9:30 20:00~24:00	Whole day
SB8 port	0℃~10℃	0:00~9:00 20:30~24:00	0:00~11:30 18:00~24:00
SB9 port	0℃~10℃	0:00~9:00 20:30~24:00	0:00~11:30 18:00~24:00
SB10 port	0℃~10℃	0:00~8:30 20:50~24:00	0:00~11:45 18:30~24:00
SB11 port	0℃~10℃	0:00~8:00 21:00~24:00	0:00~10:30 19:00~24:00

According to Table 4 below, the suitable temperature difference between the top and bottom plates for different girder assemblies is different, and the corresponding assembly time on the same day is also different. Summer is not suitable for assembly work for a long time. Before 9:00 in the morning, the girder body was not directly exposed to the sun, and the temperature difference between the top and bottom of the girder body did not reach the limit. In the afternoon, the suitable working time is around 20:00. Winter is suitable for longer homework hours, and can even be done around the clock. The box girder assembly operation should be determined based on the temperature difference and operation time determined in Table 4. combined with factors such as temperature changes on the day.

5. Conclusion

(1) Temperature difference has a significant impact on the angle between girders. Under different temperature difference modes, the angle between girders may exceed 0.1194 ". Once this limit is exceeded assembly operations cannot be carried out, which affects normal construction. Therefore, temperature difference factors should be considered in actual construction.

(2) When assembling girders in different sections, the temperature difference between the top and bottom of the girder and different time periods should be reasonably selected for the operation. The temperature difference limit and operation time of the top and bottom of the girder should be reasonable selected to ensure the smooth assembly of the girder

(3) This study is only based on the positive temperature difference along the height of the girder. To consider the effects of transverse and negative temperature differences on the girder, relevant work should be carried out in the next step.

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If any, should be placed before the references section without numbering.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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