Study on The Influence of Negative Temperature Gradient of U-shaped Girder of Rail Transit in Winter

Xu Dong¹, ², *, Guofu Sun¹, Gangnian Xu¹

¹School of Civil Engineering, Shandong Jiaotong University, Jinan 250357, China
²China Railway 14th Bureau Group Co.,Ltd, Jinan 250101, China

*Corresponding author e-mail: 149013293@qq.com

Abstract. To study the influence of negative temperature gradient of U-shaped girder of rail transit in winter season, a U-shaped rail transit girder was researched in Qingdao. The temperature self-stress of the mid-span section were observed for a 48-h period during the winter. The temperature stress were obtained which caused by vertical and transverse temperature gradient at maximum temperature difference time. The temperature effects caused by different temperature gradient models were analyzed and compared with actual results using a finite element model. The results show that, given the temperature effect, the compressive stress of the mid span section of the structure is small, the web and bottom slab have a greater longitudinal tensile stress which should be considered in the design.

1. Introduction
A pre-stressed concrete structure is significantly affected by environmental temperature changes and material heat conduction, which generate a non-uniform temperature field and temperature stress, the latter of which is considered an important reason for the cracks in a structure [1-3]. Meanwhile, study results have indicated that a structure has positive temperature gradients caused by a temperature increase in the environment, resulting from the surface temperature of the structure being higher than the internal temperature, and that the effects of a negative temperature gradient caused by a decrease in temperature should not be ignored. Therefore, the problem of structure negative temperature gradient effect has been the focus of research in recent years [4-5].

A U-shaped girder is a new type of structure used in urban rail transit viaduct bridges in China, as shown in Figure 1, and was recently derived from a foreign groove girder. Compared with many traditional bridge components, such as T-shaped and box girders, a U-shaped girder has an open thin-walled U-shaped section, which is composed of a bottom slab, web, and flange slab. Therefore, the distributions of the temperature field can be affected by the open U-shaped section and have their own particularity. If temperature gradient models based on a box girder are applied to the design of a U-shaped girder, significant errors will occur in determining the actual temperature difference effect.

In this paper, a polypropylene fiber concrete U-shaped girder used in the Chinese city of Qingdao was researched. The temperature self-stress of the mid-span section were observed for a 48-h period during the winter. The temperature stress were obtained which caused by vertical and transverse temperature gradient at maximum temperature difference time. The temperature effects caused by
different temperature gradient models were analyzed and compared with actual results using a finite element model. All results were shown to be significant for use in an engineering design.

2. Project Details
This study is based on the Blue Silicon Valley intercity rail transit project in Qingdao. As shown in Figure 1, U-shaped girders using pre-stressed concrete as a simple support structure with a span length of 30 m were used. At the mid-span section of the girder, the height is 1.8 m, the width of the top is 5.32 m, the width of the bottom is 3.98 m, and the thicknesses of the web and bottom slab are both 0.26 m. For the girder, polypropylene fiber concrete with a fiber dosage of 0.9 kg/m\(^3\) and a standard strength grade of C55 was adopted. Pre-stressed steel with high strength and low relaxation was used in this girder, which has a diameter of Φ 15.2 and standard strength of \(R_y=1860\) MPa.

![Figure 1. Dimensions of mid-span section (unit: mm)](image)

3. Experiment Analysis of U-Shaped Girder Temperature Field
To obtain the influence of negative temperature gradient, in this study, a continuous 48h observation of the temperature stress of a U-shaped girder was carried out in January, which is a typical winter month. The 48-h test period began at 20:00 on Jan. 13, and measurements were taken at 2h intervals. The direction of the U-shaped girder at the test site was northwest-southeast. As shown in Figure 2, the number of strain measuring points were 32. Embedded strain gauges were used to monitor the strain of the bottom slab, and resistance-type strain gauges were used to monitor the strain of the other parts. Photograph of the testing is shown in Figure 3.

![Figure 2. Layout of measurement points](image)
4. Comparative Analysis of Temperature Difference Effect

To study the temperature difference effect of the sunshine temperature gradient on a U-shaped rail transit girder, the finite element analysis (FEA) program ABAQUS was used to establish a three-dimensional FEA model of a U-shaped girder for analyzing the sunshine temperature difference effect. The numerical model adopts a C3D8R eight-node linear hexahedron element, divided into 207,176 nodes and 168,000 units. The FEA model is shown in Figure 4.

Because a U-shaped girder is a simple support structure, it generates temperature self-stress for the temperature difference effect. The FEA results of the U-shaped girder temperature effect were calculated using the temperature gradient models proposed in the lecture [5] and in the railway bridge code [6]. Taking the measured values generated at 16:00 on Jan. 13 as a benchmark, the measured result of the temperature difference effect, generated at 8:00 on Jan. 15, could be obtained. The FEA results of the longitudinal, horizontal, and vertical temperature stresses of different gradient models were compared with the measured results, as shown in Tables 1 through 3.

As the tables indicate, the temperature stress calculated using the temperature gradient model proposed in the lecture [5] is consistent with the distribution law and measured values. Although the measured values of the individual measurement points were slightly larger than the FEA results, owing to the impact of the test environment and the level of precision, it did not affect the overall analysis results. The longitudinal stress calculated based on the railway bridge code showed a greater difference from the measured values because the railway bridge code model is based on a box girder whose temperature difference of the top slab is higher, whereas the temperature differences of the web and bottom slab are lower for the top slab shade. The temperature gradient models proposed in the lecture
consider the temperature gradient model of the web and bottom slab, and thus the temperature effects were basically consistent with the measured results.

Table 1. Comparison between longitudinal temperature stress (unit: MPa)

| Location                     | No. of Measurement Points | Temperature Gradient Models | Lecture Model | Railway Code | Measured Value |
|------------------------------|---------------------------|----------------------------|---------------|--------------|----------------|
| Top Surface of wing slab     | S2                        |                            | 2.24          | 1.45         | 2.21           |
|                              | S5                        |                            | -2.42         | 1.75         | -2.22          |
| Top Surface of Bottom Slab   | S17                       |                            | 0.91          | -0.49        | 1.21           |
|                              | S18                       |                            | 1.04          | -0.51        | 1.14           |
|                              | S19                       |                            | 0.93          | -0.49        | 0.95           |
| Undersurface of Bottom Slab  | S28                       |                            | 1.15          | -0.42        | 1.10           |
|                              | S29                       |                            | -0.73         | -0.43        | -0.69          |
|                              | S30                       |                            | -0.87         | -0.43        | -0.72          |
|                              | S31                       |                            | -0.79         | -0.43        | -0.75          |
|                              | S32                       |                            | 1.24          | -0.42        | 1.12           |

Table 2. Comparison among transverse temperature stresses (unit: MPa)

| Location                     | No. of Measurement Points | Temperature Gradient Models | Lecture Model | Railway Code | Measured Value |
|------------------------------|---------------------------|----------------------------|---------------|--------------|----------------|
| Top Surface of Wing Slab     | S8                        |                            | 0.86          | 0.18         | 0.83           |
|                              | S11                       |                            | 1.05          | 0.77         | 0.95           |
| Top Surface of Bottom Slab   | S20                       |                            | 0.12          | 0.01         | 0.10           |
|                              | S21                       |                            | 0.14          | 0.01         | 0.11           |
|                              | S22                       |                            | 0.14          | 0.01         | 0.11           |
| Undersurface of Bottom Slab  | S23                       |                            | 0.16          | 0.01         | 0.13           |
|                              | S24                       |                            | 0.16          | 0.01         | 0.19           |
|                              | S25                       |                            | 0.18          | 0.01         | 0.12           |
|                              | S26                       |                            | 0.17          | 0.01         | 0.12           |
|                              | S27                       |                            | 0.17          | 0.01         | 0.13           |

Table 3. Comparison among vertical temperature stresses (unit: MPa)

| Location | No. of Measurement Points | Temperature Gradient Models | Lecture Model | Railway Code | Measured Value |
|----------|---------------------------|----------------------------|---------------|--------------|----------------|
| Web      | S13                       |                            | -0.01         | -0.15        | 0.01           |
|          | S14                       |                            | -0.02         | -0.17        | -0.02          |
|          | S15                       |                            | -0.02         | -0.17        | -0.02          |
|          | S16                       |                            | -0.01         | -0.15        | -0.02          |
Figure 5 through 7 show longitudinal, transverse, and vertical stress nephograms of the temperature difference effect of a U-shaped girder, respectively. As shown in Figure 5 through 7, under the influence of nonuniform temperature gradients, the compressive stress of the mid-span section of the structure is small at less than -1 MPa. A greater longitudinal tensile stress occurs at the top surface of the wing slab and the bottom slab, the maximum value of which is 2.42 MPa. The transverse tensile stress is mainly distributed on the top surface of the wing slab, the maximum value of which is 1.05 MPa. The maximum vertical tensile stress occurs at the top side of the wing slab, the value of which is 0.54 MPa. Because a U-shaped girder is a thin-walled structure, and the tensile strength is far less than the compressive strength of concrete, the longitudinal tensile stress of the bottom slab and wing slab, which are generated by the temperature gradient effect, need special attention in terms of design.

Figure 5. Nephogram of longitudinal stress

Figure 6. Nephogram of transverse stress

Figure 7. Nephogram of vertical stress nephogram

5. Conclusion
In this paper, a U-shaped rail transit girder was researched in Qingdao. The temperature self-stress of the midspan section were observed for a 48-h period during the winter. The temperature stress were obtained which caused by vertical and transverse temperature gradient at maximum temperature difference time. The temperature effects caused by different temperature gradient models were analyzed and compared with actual results using a finite element model. The main conclusions can be summarized as follows:
The temperature gradient models proposed in the lecture [5] consider the temperature gradient model of the web and bottom slab, and thus the temperature effects were basically consistent with the measured results.

Under the influence of nonuniform temperature gradients, the compressive stress of the mid-span section of the structure is small at less than -1.0 MPa. A greater longitudinal tensile stress occurs at the top surface of wing slab and bottom slab, the maximum value of which is 2.42 MPa, which are generated by the temperature gradient effect, need special attention in terms of design.

References
[1] Abid S, Taysi N and Ozakca M, Experimental analysis of temperature gradients in concrete box-girders, Construction and Building Materials, 2016, 106:523-532
[2] Xu D, Zhenquan D and Shuchen L, Research on sun light temperature field and thermal difference effect of long span box girder bridge with corrugated steel webs, Engineering Mechanics, 2017, (9):239-247
[3] Xu D, Shuchen L and Pengcheng W, Research on sun light temperature gradient effect of ballastless rail transit U-shaped beam, Journal of Harbin Engineering University, 2017, 7:1-8
[4] Yudong N, Analysis of temperature field and temperature effect for long span concrete box girder bridges in cold regions, Harbin Institute of Technology, 2013, 1-120
[5] Xu D, Fengkun C and Xiudong L, Experimental analysis of gradient of negative temperature for polypropylene fiber concrete U-shaped girder, IOP Conference Series: Materials Science and Engineering, 2020, 134-142
[6] MRPRC (Ministry of Railways of the People's Republic of China), TB 10002.3-2005 code for design on reinforced and prestressed concrete structure of railway bridge and culvert, Beijing, China Railway Publishing House, 2005