Analysis of Sunshine Temperature Field and Temperature Effect of Prestressed Concrete Beam Bridge

Liuyu Zhang*, Shufa He, Guitong Zhang, Jingwen Zhou, Lezhou Huang and Zhiguo Wang
School of Highway, Chang’an University, Xi’an, Shaanxi, 710064, China
*lyz@chd.edu.cn
Corresponding author email: 975379784@qq.com

Abstract: Temperature stress is one of the important causes of concrete structure cracking. In order to study the development law of temperature field and temperature effect of prestressed concrete beam bridge under sunshine load, taking the construction of a prestressed concrete beam bridge as an example, ADINA finite element software was used for solid simulation and compared with the measured value. The results show that the temperature curve of each point inside and outside the beam is consistent with that of the ambient temperature, but it has some hysteresis. The temperature stress distribution of the beam body calculated by using the temperature gradient in the current code is approximately the same as the measured value. The top and bottom plates are compressed, and the web plate produces large tensile stress.

1. Introduction
With the development of bridge construction, scholars at home and abroad have a deeper understanding of the temperature effect of concrete structure. Through in-depth study, it is found that the temperature load has a huge impact on the concrete structure, and sometimes the effect of temperature in the concrete structure is dominant, which is an important factor that cannot be ignored in the structural design [1,2,3]. Due to the random factors such as daily radiation intensity, bridge orientation and sunshine time, the surface and interior of the structure have uneven temperature distribution due to convection, heat radiation and heat conduction, thus sunshine temperature field is formed inside the structure, which has an impact on the structure.

Taking a prestressed concrete girder bridge as an example, this paper uses ADINA to establish a solid finite element model, introduces the temperature gradient of the beam measured in the field and the temperature gradient in the current specification [4] into ADINA Structure module for structural stress analysis, and draws corresponding conclusions through comparative analysis.

2. Establishment and analysis of finite model
For highway concrete bridge structure, the deck is generally wide, and the bridge face plate is directly affected by sunshine, while the web is shielded by the cantilever, and the temperature change on both sides is negligible, so for beam structure, sunshine temperature difference along the direction of section height can only be considered.

A 3D SOLID finite element model is established by ADINA. The concrete beam body adopts 3D-solid element, while the ordinary reinforcement and prestressed tendons are considered by using Rebar element [5].
According to reference [4], the vertical temperature curve shown in figure 1 can be used to calculate the effect of bridge structure due to gradient temperature. The maximum temperature $T_1$ on bridge surface is shown in table 1. For concrete structure, when the beam height $H < 400$, $A = H - 100$; when the beam height is $\geq 400$, $A = 300$.

![Figure 1. Vertical temperature curve.](image1)

![Figure 2. Temperature field of temperature gradient positive temperature difference.](image2)

![Figure 3. Temperature normal stress of sunshine positive temperature difference (specification value).](image3)

| Structure type                      | $T_1$ (°C) | $T_2$ (°C) |
|------------------------------------|------------|------------|
| Cement Concrete Pavemen            | 25         | 6.7        |
| 50mm asphalt concrete pavement     | 20         | 6.7        |
| 100mm asphalt concrete pavement    | 14         | 5.5        |

Table 1. Temperature base of vertical sunshine positive temperature difference calculation.
As can be seen from figure 3, under the action of sunshine positive temperature difference, the web of the beam body is under overall tension, and the tensile stress of C-C section is greater than that of A-A section. The tensile stress of C-C section near the top of the web reaches the maximum value of 2.8Mpa.

3. Live bridge tracking test

3.1. Test Scheme [6]
According to the statistical rule of early disease, the sections 2m, 9m and 13m away from the beam end of the bridge are taken as the main test section (A-A, B-B and C-C), as shown in figure 4. The sensors at 2m are arranged according to one roof, one web and one bottom plate. The temperature sensors at 9m and 13m are arranged in 7 monitoring points inside the section, and 5 measuring points are arranged on the surface of the web, as shown in figure 5.

3.2. Test results
The changes of the temperature and strain on the inside and outside of the beam under the action of sunshine load during two days from the morning of August 24 (sunny day) to the evening of August 25 (cloudy day) are statistically analyzed, as shown in figure 6 and figure 7.
As can be seen from figure 6 and figure 7, under the action of sunshine load, the overall temperature change curve of the beam inside and outside is similar to that of the ambient temperature. Compared with the ambient temperature change, the temperature change of the beam has a certain hysteresis, about 2~6 hours, and the hysteresis decreases with the increase of the distance from the bottom of the beam. In terms of strain, since the temperature of the roof (point 1) is higher than that of the pedicle axil (point 2), the concrete expansion at the flange plate will be restrained by the concrete at the bottom corner of top plate. Therefore, the flange plate position will be under compression, and the concrete at the bottom corner of top plate will be under tension. The strain peak of concrete at the top of the roof is between -100με~120με, while the top of the web adjacent to the roof (point 2) will be subjected to greater tensile stress, with a strain peak of 117με. The strain peak at the bottom corner of top plate of the surface of the beam is 15με, and the strain peak at the other places is about -60με.

4. Temperature stress analysis
The measured temperature gradient load was introduced into ADINA finite element model and the temperature stress generated by sunshine temperature gradient was calculated by ADINA Structure module.
As can be seen from figure 8, under the action of the measured temperature gradient load, the temperature stress distribution law of the concrete T-beam is basically consistent with the temperature normal stress generated by the gradient temperature specified in the current code. When the top and bottom plate are under compression, the web as a whole is under tension. The tensile stress at the top of the web is greater than that at the bottom of the web, and the tensile stress at the top of the C-C section web is 3.4Mpa.

5. Conclusion
(1) Under the action of sunshine load, the overall temperature change curve of the beam body is similar to that of the ambient temperature. Compared with the ambient temperature change, the temperature change of the beam body has a certain hysteresis, about 2~6 hours, and the hysteresis decreases with the increase of the distance from the bottom of the beam.

(2) Under the action of the measured temperature gradient load, the temperature stress distribution law of the concrete T-beam is basically consistent with the normal stress generated by the gradient temperature specified in the code. The tensile stress at the top of the web is the largest, and its magnitude cannot be ignored, which should be strictly considered in the design.

Acknowledgments
First and foremost, I wish to express my sincere and deep gratitude to my supervisor, Professor Liuyu Zhang, for his inspiring instructions, earnest encouragement and great patience he has offered to me. I was especially touched and encouraged by his detailed comments and suggestions when finishing the paper. I would also like to express my thanks to my friends Guitong Zhang and Jingwen Zhou for their sincere support.

References
[1] Minxin G. (1986) Crack and calculation of sunshine temperature load and temperature stress of concrete bridge. China Railway Science, 02: 27-34.
[2] CALEBUICK F. (1981) Effect of Solar Radiation on Bridge Structure. LIU Xing-fa, et al. translated. China Railway Publishing House, Beijing.
[3] Junying G. (2010) Analysis of sunshine temperature difference effect of prestressed concrete box girder. China Railway, 01: 52-54.
[4] General Specifications for Design of Highway Bridges and Culverts (JTG-2015). China Communication Press, Beijing.
[5] ADINA R&D,Inc. Theory and Modeling Guid.2016.
[6] Yanshi S, Changming H, Yonghui L. (2008) Crack control and temperature monitoring analysis of mass concrete in cushion cap. Building Structure, 12: 95-97.