Refined Calculation and Demonstration for Sunshine Temperature Difference Effect of Long Span Continuous Beam

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Abstract. The continuous rigid frame bridge of Jiagai River Bridge is (100 + 192 + 100)m, with a main span of 192m, which will break the historical record of 176m of Chaoyang Jialing River Bridge and become the largest continuous rigid frame bridge of single track railway in China. The single track railway continuous rigid frame bridge has the characteristics of large load, poor stability and high prestress requirements. The temperature difference in sunlight will produce temperature deformation and temperature stress in the concrete box girder bridge, which will affect the linear monitoring measurement results. In particular, the sunshine temperature difference will produce nonlinear temperature gradient in the vertical and transverse direction of the cross section of the statically indeterminate box girder bridge, resulting in the generation of temperature self stress and temperature secondary stress. This kind of temperature stress is often large, which leads to the cracking of concrete and even endangers the normal operation in the future. This paper studies the calculation of temperature field, temperature stress and temperature deformation of concrete box girder caused by solar radiation, and compiles a program to realize the visual calculation of sunshine temperature effect.

1. Introduction
The Jiagai River Bridge is a (100+192+100)m continuous rigid frame bridge. Its main span of 192m will refresh the historical record of the 176m main span of the Chaoyang Jialing River Bridge and become the continuous rigid frame bridge with the largest span of a single-track railway in our country. The bridge body is a single box single room, variable height, variable cross-section box girder. The girder has a total length of 393.9m and a beam width of 10.3m. The bridge is divided into 26 sections. The 18m beam section in the middle of the middle span, 13.95m at the end of the side span and the beam section at the top of the main pier are equal-height beam sections. The beam height at the middle span is 6.90m, and the beam height at the middle pier is 13.20m. The beam bottom of the remaining beam sections is quadratic parabola. Y=6.9+6.3X²/81² (m). The height from the bottom of the rail to the top of the beam is 0.65m. The thickness of the top plate is 62cm, and the thickness of the bottom plate is changed according to the parabola within the range of the beam height changing section. The bottom plate thickness at the end block of the side span gradually changes from 51cm to 120cm; the thickness of the web plate is 60~120cm, which changes in a straight line, and the thickness of the web at the end block of the side span gradually changes from 60cm to 120cm, and there are 6 horizontal partitions in the beam body. The continuous rigid frame bridge of single-track railway has
large load, poor stability and high prestress requirements, and it is difficult to control various stresses during the construction process. We study the temperature difference and temperature stress control technology in the concrete box girder bridge caused by the solar temperature difference during the construction of the continuous rigid frame beam, solve the temperature stress problems encountered in the construction, further optimize the construction plan, ensure the smooth progress of the construction, and ensure that the high pier and long-span rigid frame bridge is completed safely and efficiently, which provides a reference for the control of solar thermal stress for the design and construction of future long-span continuous rigid frame bridges.

Scholars at home and abroad have done a lot of research and exploration on the temperature field and temperature stress of concrete box girder bridges, and accumulated a lot of valuable experience, which made its calculation theory gradually improved [1-6]. However, in the selection of the temperature field mode, the regulations of the national standards are different. Even the temperature field mode selected by the domestic highway bridge code and the railway bridge code is completely different, so that under the same conditions, the calculation results obtained by the site of the temperature specified in the two specifications will have the opposite temperature stress on some control sections. This makes it appear in the engineering design which temperature field is reasonable, and determining a reasonable temperature field is the prerequisite for the calculation of temperature stress, especially for areas with strong solar radiation and significant regional differences in temperature fields. Field research can be followed by scarce data [7-15]. Therefore, it is of great significance to study the temperature effect of solar radiation on the box structure.

2. Program design for calculating the temperature effect of sunshine

2.1. Basic ideas
The essence of temperature field analysis is to solve the differential equation of heat conduction according to certain initial conditions and boundary conditions. Among them, the initial condition is the initial temperature distribution at the starting point, which is relatively easy to determine. The boundary conditions reflect the heat exchange between the concrete bridge structure and the natural environment through its surface, and are affected by various complex meteorological factors. Therefore, establishing a reasonable and simplified heat transfer boundary condition that can reflect the actual situation is the key to solving the temperature distribution of the concrete bridge structure.

In addition to meteorological factors, the heat exchange between the concrete bridge structure and the outside world is related to the geographic location, the surrounding topography and geomorphology, and the geometric characteristics of the bridge itself. It is very difficult to accurately simulate the heat exchange process, but from the perspective of controlling the temperature load, it is only necessary to analyze the extreme meteorological conditions that cause the structure to produce the most unfavorable temperature load. Regarding the temperature effect of sunlight on concrete bridges, the temperature response under sunny weather, large temperature changes and low wind speeds is studied. The main meteorological factors that affect the temperature distribution of the structure are relative to the solar radiation intensity, temperature changes and wind speed. It is relatively clear and can accurately describe the boundary conditions of the heat conduction problem.

2.2. Secondary development based on ANSYS
The ANSYS program is a powerful and versatile finite element analysis software. At the same time, it also has good openness. Users can perform function expansion and system integration on the standard ANSYS version according to their own needs. The user version of ANSYS program that the user needs. At the same time, ANSYS provides secondary development languages, such as User Interface Design Language (UIDL) and Parametric Design Language (APDL). UIDL is a language for ANSYS to provide users with special programming interface design. Users can add and modify some group items in the graphical user interface (GUI) by changing the UIDL control file of ANSYS to achieve the purpose of developing a graphical interface. APDL language can complete various functions
realized in GUI mode in ANSYS, and users can realize various functions by editing APDL command stream. In the analysis of some complex problems, APDL language is more convenient and GUI mode.

This article is based on the ANSYS software platform, using TCL/TK scripting language to facilitate the development of various graphical interfaces. Use ANSYS built-in TCL/TK interpreter to execute user-developed TCL/TK program, generate the required graphical interface, data transfer can be realized through TCL/TK and ANSYS, and use TCL/TK interface to execute corresponding ANSYS commands to achieve the analysis of the problem purpose. The final development and formation of the "Concrete Box Girder Temperature Stress Analysis System" is shown in Figure 1 and Figure 2:

3. Case analysis
The secondary-developed "Concrete Box Girder Thermal Stress Analysis System" is used to calculate the sunshine temperature effect of the Jiagai River Bridge, and the calculation results are compared with the field measured data to verify the accuracy of the "Concrete Box Girder Thermal Stress
Analysis System" and practicality.

3.1. Arrangement of temperature monitoring points
Select the typical cross section of the Jiagai River Bridge for continuous and uninterrupted temperature observation. The temperature measurement points and layout schemes used in the monitoring are shown in Figure 3. A total of 32 temperature measurement points are arranged inside and outside the box.

![Figure 3. Layout of box girder temperature measurement points (unit: cm).](image)

3.2. Analysis of temperature field monitoring results
The total number of data collected in this observation is 624 groups, more than 56,000. According to a large number of documents and codes, the surface temperature of the top plate of the ballasted box girder is almost constant or changes little throughout the day, and only needs to be effected along the beam width. The distribution law of the measured temperature and the ambient temperature at each location is shown in Figure 4-9.

![Figure 4. Measured temperature and ambient air temperature on the surface of the top plate.](image)
Figure 5. The measured temperature and ambient air temperature at the measurement points on the lower surface of the roof.

Figure 6. Temperature of measuring points on the top plate of different longitudinal cross-sections.

Figure 7. Temperature and ambient air temperature at the measurement point of the web on the west side.

Figure 8. Temperature and ambient air temperature at the measurement point of the web on the east side.
It can be seen from the monitoring results that the concrete temperature change law at each measuring point on each part of the box girder is basically the same, there is no lateral temperature difference, the temperature distribution is close, and the change law of the air temperature outside the box is also basically the same, showing an obvious sinusoidal change trend.

It can be seen from Fig. 10 that the maximum concrete temperature on the upper edge of the box girder roof appears from 2 pm to 3 pm, and the maximum positive temperature difference along the thickness of the slab appears from 1 pm to 4 pm. The maximum negative temperature difference of the top slab along the thickness direction is small, about 1°C, the time when the surface concrete temperature on the top slab reaches the daily extreme value is about 2.5 hours later than the time when the temperature outside the box reaches the daily extreme value, and the temperature changes further inwards along the roof. The smaller the amplitude, this is because concrete is a poor conductor of heat. When the external temperature and other boundary conditions change, it will take a certain time to affect the concrete inside the slab. This article calls this phenomenon the temperature field of the concrete slab. Time lag. The time lag of the temperature field of the concrete slab is the root cause of the temperature difference of the slab.
Figure 11. The maximum negative temperature difference of the top plate along the thickness direction.

It can be seen from Figure 11 that the maximum temperature difference of the roof concrete along the slab thickness can reach about 20°C. Taking into account that the thickness of the protective layer at the measuring point is about 10cm, the maximum temperature difference of the top slab may exceed 25°C. The concrete close to the surface of the top slab is greatly affected by atmospheric temperature and the temperature is relatively high.

Figure 12. Comparison of measured temperature at different depths at the same location on the west side of the web.

Figure 13. Comparison of measured temperature at different depths at the same location on the east side of the web.

The laws reflected in Figure 12 and Figure 13 are basically the same. Regardless of the south web or the north web, the measured temperature difference between the measurement points close to the inner surface of the box and the outer surface of the box is very small, not exceeding 2 °C. This shows that due to the shielding effect of the wing plate in summer, the web is exposed to strong solar radiation. Cannot be affected by direct sunlight. "The daily temperature change range of the concrete temperature at the web measurement point is less than 3°C. The measured temperature change range
of the temperature measurement point on the web inner wall is relatively small, which is basically the same as the temperature change in the box, but the outside of the box is covered. The change in temperature in shade is much higher than the change in concrete temperature on the outer wall of the web.

3.3. Analysis of temperature field simulation results
The structural parameter design language APDL of ANSYS software is used to calculate the sunshine temperature effect calculation program, and the actual size of the 2-2 cross-section of the box girder buried temperature sensor in the Jiagai River is used for calculation, and the APDL parametric modeling is used to establish the space finite element. The model is calculated and analyzed, and compare with the measured data above. Due to the poor thermal conductivity of concrete materials, a certain lag time is required, so that the initial temperature field inside the concrete gradually weakens and its temperature changes periodically with the boundary conditions in constant amplitude, which is in a thermal steady-state fluctuating state, not at the beginning. Change immediately. Therefore, the definition of the initial temperature field is very important for the calculation of the temperature field. Therefore, when determining the initial conditions for the calculation of the sunlight effect, we choose the moment when the overall temperature distribution of the concrete structure is relatively uniform after the box girder has been observed for several consecutive days (About 1h before sunrise), that is, the measured box girder temperature at 5 o'clock in the morning is used as the initial temperature. It can be seen from Figure 14:
Figure 14. Cross-sectional temperature distribution at different times.

1) Affected by strong solar radiation and rising temperature during the day, heat is continuously transferred from the outer surface of the concrete to the inside of the concrete, making the outer temperature higher than the internal temperature and accumulating a large amount of heat in the concrete;

2) At night, due to the disappearance of solar radiation and the gradual decrease in temperature, the outer surface temperature decreases, and the heat continues to expand into the interior of the concrete. However, due to the poor thermal conductivity of the concrete, the temperature of the box girder is in a non-uniform state most of the time until after the entire night. The box girder temperature reaches a more uniform state at 06:00 in the morning;

3) After 6:00 in the morning, the temperature starts to rise after sunrise. When the sun just rises, the radiation intensity is weak, and the temperature along the thickness of the plate is roughly uniform. After that, the outer surface temperature begins to rise higher than the inner temperature.

3.4. Comparative analysis of monitoring results and simulation results
Comparing the numerical simulation results of the surface temperature of the top plate with the actual test results, it is found that the calculated data is in good agreement with the measured data, and the error is basically within 10% (as shown in Figure 15). In the comparison between the calculated and measured values of the surface temperature of each slab in Figure 15-18, the calculated value of the ceiling concrete temperature is in good agreement with the measured value, and the absolute error between the calculated value and the measured value does not exceed 2°C. The surface concrete on the top slab reaches the highest daily temperature or the lowest temperature 3-4 hours earlier than the lower surface of the top slab; the absolute error between the calculated value and the measured value of the web concrete temperature is about 2°C, and the concrete on the outer surface of the web reaches the highest daily temperature which is the latter. The lowest temperature is 4-5 hours earlier than the inner surface. The concrete on the outer surface of the web reaches the highest daily temperature at about 19:00, which is about 2.5 hours later than the highest temperature on the outer surface of the top.
slab; the absolute value of the calculated and measured values of the concrete temperature of the bottom slab. The error is about 2°C. In summary, it can be judged that the calculated value is more consistent with the actual measured value, and the difference in the result is small.

Figure 15. Comparison of calculation and actual measurement of the surface temperature of the top plate.

Figure 16. Comparison of calculation and actual measurement of bottom plate surface temperature.

Figure 17. Comparison of calculated and measured web surface temperature.
4. Conclusion
(1) We use APDL, UIDL and script language TCL/TK embedded in ANSYA for secondary development program, set up real-time calculation module of bridge sunshine temperature field and calculation module of sunshine temperature difference effect, and establish box girder space finite element temperature field analysis model. It is used for the detailed analysis and calculation of the effect of solar temperature difference in the construction of concrete bridge structures, which can solve the difficult problem of accurate simulation and analysis of the whole process of heat exchange. It can be accurate by using factors such as solar radiation intensity, temperature change and wind speed as boundary conditions, describing heat conduction problems in a detailed manner.

(2) We compare the temperature results of numerical simulation with the measured data. The agreement between the two is relatively high, the error is basically within 10%, and the error at the extreme point is smaller. The model calculated by this program simulates the temperature field of the concrete box girder by simulating the heat exchange conditions on the outer surface of the box girder, and realizes the visual calculation of the temperature effect of sunlight. This method is feasible in actual analysis on account of the accurate and reliable calculation result, therefore, it can be popularized and used in similar projects.

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Figure 18. Comparison of calculation and actual measurement of the surface temperature of the inner roof.
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