Study on Sunshine Temperature Field of Concrete Box Girder Based on Meteorological Parameters

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Abstract: In order to analyze the variation law of sunshine temperature field of low height concrete box girder, Tangshan second ring road cable-stayed bridge was used as the engineering background, the finite element method combined with the field temperature measurement is used to analyze the sunshine temperature field of the concrete box girder by using the weather observation data at the bridge site. The results show that: the temperature field of sunshine in the box girder can be directly analyzed using the meteorological observation data at the bridge site, and the calculation precision can meet the engineering requirements.

1. Introduction

Studying the solar temperature field of the structure is a prerequisite for studying the temperature effect of the structure\(^1\). For the concrete bridge structure in the actual environment, the main factors affecting the sunshine temperature field are solar radiation, atmospheric temperature, atmospheric scattering, wind speed and geographical location. The changes are more complicated\(^2\). Aiming at the temperature field of the bridge structure, relevant scholars have done a lot of work in theoretical research, statistical research and numerical simulation. However, most of the theoretical studies can not consider the transient temperature field of the structure, and usually artificially amplify the static temperature load to consider the temperature effect of the bridge, so it can not reflect the temperature field of the bridge structure in the actual environment.

Based on the existing research, this paper takes the Tangshan Second Ring Road concrete cable-stayed bridge as the engineering background. Based on the meteorological parameters of the bridge site, the finite element software Midas/Fea was used to analyze the temperature field of the low-profile single box three-chamber concrete box girder. The distribution law of temperature field of concrete box girder is summarized, which provides reference for the calculation and analysis of temperature field and temperature effect of similar bridges in the same area.

2. Temperature field finite element analysis theory

At some point, the description of the temperature at all points inside the concrete is called the temperature field of the concrete at that moment. In a Cartesian coordinate system, the temperature field of a concrete structure can be expressed as a function\(^3\):

\[
T = f(x, y, z, t)
\]  (1)

where, \(t\)—time, \(x, y, z\)—Coordinates of various temperature points in concrete

For the three-dimensional concrete box girder structure, according to the conservation of energy, the box beam heat conduction differential equation can be expressed as follows\(^2\):

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where, $\frac{Q}{c_p \rho}$ is thermal conductivity (m²/s); under the premise that the concrete is uniform, isotropic and continuous, $\lambda, c_p, \rho$ is constant. If the concrete temperature does not change with time, $\frac{\partial T}{\partial t} = 0$, then $T = f(x,y,z)$ is thermostatic field; If the concrete temperature changes with time, $\frac{\partial T}{\partial t} \neq 0$, then $T = f(x,y,z,t)$ is unsteady temperature field; If the temperature field in the z direction of the concrete remains constant, $\frac{\partial T}{\partial z} = 0$, then $T = f(x,y,z,t)$ was simplified to a flat temperature field.

According to the ASHRAE clear sky model, the solar radiation received by the concrete box girder is divided into direct radiation, scattered radiation and ground reflected radiation [4]. For concrete box girder, the roof and side webs are both directly radiated by the sun and convective heat transfer and radiative heat transfer with the surrounding atmosphere. Comprehensive considerations:

(1) External boundary conditions of concrete box girder:

$$
\lambda \left( \frac{\partial T}{\partial n} \right) = q_r + q_s + q_c
$$

(3)

$$
\lambda \left( \frac{\partial T}{\partial n} \right) = q_r + h_c (T_a - T) + h_r (T_s - T) - q_{ra}
$$

(4)

In the Midas/Fea thermal analysis process, different types of boundary conditions need to be converted into the same boundary condition. If the second and third types of boundary conditions exist in equation (4), then the third type of boundary condition is used to represent the second type of boundary condition:

$$
\lambda \left( \frac{\partial T}{\partial n} \right) = h (T_s - T)
$$

(5)

where: $h$ is comprehensive heat transfer coefficient, $h = h_c + h_r$; $h_c$ is heat transfer coefficient between concrete and surrounding environment; $h_r$ is radiation heat transfer coefficient; $T_s$ is integrated temperature of air medium, $T_s = T_a + \frac{q_r - q_{ra}}{h}$.

(2) Box girder internal boundary condition

The inner boundary only has the heat exchange between the inner wall concrete and the air inside the box. The daily temperature change inside the box beam is small, and there is basically no air flow in the box. Therefore, the heat transfer coefficient is calculated according to $v=0$ m/s, and the boundary condition can be expressed as:

$$
\lambda \left( \frac{\partial T}{\partial n} \right) = h \left( T_{s^*} - T \right)
$$

(6)

where: $T_{s^*}$ is box girder inside temperature. If there is no measured data, the external average temperature can be increased by 1.5°C[5].

It can be known from equations (5) and (6) that solving the boundary condition of the box beam temperature field is to establish an integrated array of air medium temperatures.

3. Project Overview

Tangshan second ring road cable-stayed bridge is a 2×115m single tower cable-stayed bridge. The span is composed of (34+81+115) m, as shown in Figure 1.

The stiffening beam is made of equal height concrete box girder. The standard section box girder top
is 1900cm wide, the beam height is 150cm, the top plate is 30cm thick, the bottom plate is 25cm thick, the middle web is 30cm thick, and the side web is 90cm thick. At the main tower, the top of the box girder is 1650 cm wide, the beam height is 150 cm, the top plate is 30 cm thick, the bottom plate is 40 cm thick, the middle web is 30 cm thick, and the side web is 130 cm thick. The main beam structure is shown in Figure 2.

The geographical coordinates of the Tangshan Second Ring Road cable-stayed bridge are located at N39°44′29.45″, east longitude E118°10′30.61″. According to the observation data of the Tangshan Meteorological Bureau, the average annual temperature is 11.3°C, the minimum temperature is -22.7°C (January 28, 1983), and the highest temperature is 39.6°C (June 10, 1972). The dominant wind direction in this area is controlled by the monsoon, with more northeast winds in winter and more southwest winds in summer.

The short-term and seasonal temperature curves of the test sections of the concrete box girder are measured by the main beam embedded temperature sensor. The measuring point arrangement of a test section of the main beam is shown in Figure 3. A total of 39 temperature measuring points are set (only the temperature of the top floor temperature measuring point at the center line of the box girder is given).

4. Finite element analysis of box beam temperature field

For the temperature monitoring section of the concrete box girder, the simulation analysis of the sunshine temperature field was carried out using Midas/Fea and select the unfavorable time period of May 31, 2017 (summer high temperature) all day.

4.1. Selection of calculation parameters

The concrete density is taken from the field measured value of 2600kg/m³. The concrete specific heat value is 985J/kg·K; The thermal conductivity is inversely calculated by the formula to 2W/m·K through the field measured temperature data; The solar radiation absorption coefficient is taken as 0.65; The solar radiation intensity of each wall at different times is calculated according to the derivation formula of the literature[6]. The comprehensive heat transfer coefficient of the box girder is calculated according to the formula on May 31[6]. According to the measured data, since the temperature difference between the inside and outside of the box girder is larger than that at night, the most unfavorable temperature field occurs during the daytime, so only the transient temperature field analysis of the box girder from 5:00 to 20:00 is performed.

4.2. Comparison of measured values and calculated values

In order to verify the accuracy of the finite element model analysis, a representative measuring point is
selected within the range of the top and bottom of the box girder to compare the measured value with the calculated value, the results are shown in Fig. 4.

![Graphs of Measuring Point 1 and Measuring Point 13](image)

Fig. 4 Comparison of Measured and Calculated Temperature Time-history Curves at Measuring Point 1 and 13 of May 31, 2017

Fig. 4 is the comparison of measured and calculated temperature time-course curves between measuring point 1 and measuring point 13 on May 31. It can be seen from the figure that the temperature measured value of the box girder top plate (measuring point 1) and the box girder bottom plate (measuring point 13) is basically consistent with the theoretically calculated value, and the maximum temperature difference is within 4 °C, which is in good agreement.

Through comparative analysis, it can be seen that the environmental meteorological data of the concrete box girder is used to simulate the sunshine temperature field, and the calculation results are basically consistent with the measured values. The method can be used for the temperature prediction calculation of the actual concrete box girder.

5. Summary of the temperature field law of box girder

Figure 5 and Figure 6 show the temperature variation of each measuring point on the top and bottom of the box girder with time. It can be seen from the figure that the temperature of each measuring point of the top and bottom of the box girder does not change much between 5:00 and 12:00. This is because the geographical coordinates of the cable-stayed bridge are located at N39°44′29.45″, east longitude E118°10′30.61″, the sunlight in this period is not directly on the surface of the box girder, so the solar radiation and atmospheric scattering intensity are weak; During the calculation period from 12:00 to 20:00, the temperature of each point in the top and bottom of the box girder gradually decreases with the increase of the distance between each point and the outer surface of the box girder, and the appearance time of the temperature peak is also pushed back. The maximum temperature distribution of the bottom plate appears around 18 to 19 o'clock; The top of the box girder has the longest time to receive solar radiation, so the surface temperature changes the most. The highest temperature distribution occurs earlier than the bottom of the box girder and appears around 17 to 18 o'clock. The temperature of the measuring point 1 on the top surface of the box girder is about 10 °C higher than the measuring point 13 on the bottom surface of the box girder. This is because the box girder roof directly receives the radiation from the sun, and the surface temperature change of the box girder floor is only related to the atmospheric temperature and the thermal radiation of the box girder itself. Under the action of solar radiation, the surface temperature of the bottom of the box girder slowly increases with the increase of the atmospheric temperature near the bottom of the box girder; During the calculation period from 12:00 to 20:00, the temperature variation within the top of the box girder decreases with the distance from the top of the box girder, while the temperature variation of each measuring point in the bottom of the box girder is basically the same.
Fig. 5 Time History Curve of Temperature Change at Each Measuring Point of Box Girder on May 31, 2017

Fig. 6 Time History Curve of Temperature Change at Each Measuring Point of Box Girder on November 30, 2017

Fig. 7 is a temperature distribution curve along the center line of the web of the box girder and the center line of the box girder occurs at a time (18:00). It can be found that on May 31 and November 30, the concrete in the range of about 0.25 m (0.00-0.25 m) from the top of the box girder web is subjected to a temperature difference of about 30°C and 10°C, respectively. In the range of 1.0 m (0.25 m to 1.25 m), the concrete temperature difference is small, and the concrete in the range of about 0.25 m (1.25 m to 1.50 m) at the bottom is subjected to a temperature difference of about 10°C and 3°C, respectively; For the top plate at the center line of the box girder, the temperature difference of 20°C and 8°C is also only in the range of 0.25 m thick, and the bottom plate also withstands the temperature difference of 7°C and 4°C in the range of only 0.25 m thick. Therefore, it can be found that the variation of the web of the concrete box girder is larger than that of other locations under the sunshine temperature field.

6. Conclusion

(1) Through the simulation calculation and actual measurement of the box beam sunshine temperature
field, it can be known that the sunshine temperature field of the concrete box girder can be accurately simulated by using the measured meteorological data at the bridge site. The cumbersome steps of obtaining the temperature field of the box girder by using the embedded temperature monitoring component in the box girder are avoided.

(2) The method of predicting the temperature field distribution of concrete box girder by using the meteorological parameters of the bridge site can provide reference for the study of the same type of concrete box girder temperature field.

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