Temperature Effect of Railway PC Part Cable-stayed Bridge Based on Long-term Monitoring

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Abstract. The natural environment in which bridges are located varies widely. In order to ensure the normal use of the pylon structure, it is necessary to study the influence of different external environmental factors on the temperature field and temperature effect of the pylon. The purpose of this paper is to study the temperature effect of a cable-stayed bridge in the PC part of the railway based on long-term monitoring. The relevant theories of temperature field and temperature stress analysis are summarized, and the main girder section temperature monitoring scheme is designed according to the interpolation fitting criteria. As the comparative weak radiation day temperature data, the temperature variation law of the box girder section is analyzed, and the temperature gradient fitting curve is obtained by the regression fitting method. The temperature boundary is established according to astrophysics and heat transfer theory, and the temperature field distribution and temperature stress state of the main beam are analyzed by ANSYS two-dimensional box girder section model and Midas/Civil full bridge model. The experimental results show that the solar short-wave radiation is a The main factor that causes the temperature difference of box girder section.

Keywords: Long-term Monitoring; Railway Cable-stayed Bridge; Temperature Effect; PC Part.

1. Introduction

It stands out in the domestic bridge construction and becomes one of the main bridge structures selected [1-2]. However, it has been difficult to accurately simulate the effect of temperature on concrete beam structures, and the temperature effect has a great influence on concrete bridges, resulting in problems such as excessive displacement of bridge bearings and concrete temperature cracks [3-4]. These problems will directly affect the normal use of bridge construction and endanger the structural safety. The prestressed section of the cable tray computer has the characteristics of high rigidity, small deformation, strong covering force, beautiful appearance and simple maintenance [5]. Among them, the cable-stayed bridge of the PC section of the prestressed steel rail has higher rigidity requirements, and the main beam is mostly a complex box-shaped structure; the section is generally larger, and the upper and lower plates and masts are generally thicker. Under the action of sunlight, the concrete box girder has an obvious temperature difference, and the temperature has a significant effect; while some wired bridges are affected by the cable-girder temperature difference, which also has a significant impact on the stressed structure [6-7].

With the continuous advancement of bridge technology, the design and construction of cable-stayed bridges are also constantly improving and developing [8]. Hashemi S investigated the effect of 5 different traffic load cases on the maximum response of a cable-stayed bridge under 8 different explosion scenarios and assessed the likelihood of gradual collapse. It was concluded that the configuration of the traffic load on the bridge can vary the maximum action on the different components by up to 30%. Cable loss or anchorage zone failure under blast load scenarios is observed independently of the traffic load distribution. Meanwhile, in some explosion scenarios, bridges may gradually collapse due to cable loss [9]. Le H V constructed a finite element model of a cable-stayed bridge, and by changing boundary conditions and cable tension, time series displacements under periodic temperature loads were obtained under certain structural conditions. Feature extraction and comparison procedures are then applied to the obtained displacement time series. The results show that the Mahalanobis distances of the eigenvectors configured by the estimated AR and MA coefficients show significant changes under both boundary conditions and cable tension changes [10].

Therefore, it is very important to study the temperature effect of the PC part of the cable-stayed bridge of the railway under the sun [11].

In this paper, the related theories and common analysis methods of temperature field effects are studied. By sorting out, comparing and analyzing the temperature data measured on site in the projects under construction, the variation law of the temperature of the main beam section, the cable tower section and the stay cable temperature of the concrete cable-stayed bridge over time is obtained; and the actual cable beam temperature is fitted. Difference, temperature gradient of main beam section, and temperature gradient of cable tower section. The finite element model of the full bridge is established according to the design materials, and the temperature field fitted by the field measured data is used to simulate the influence of each temperature field change on the support reaction force and displacement under the bridge state, and divide the main and secondary temperature influence factors. At the same time, the most unfavorable temperature load combination is obtained, which provides a reference for the design and selection of the bearing of the same type of cable-stayed bridge in the future.

2. Research on Temperature Effect of Railway PC Part Cable-stayed Bridge Based on Long-term Monitoring

2.1. Construction Control Characteristics of Cable-stayed Bridges

Cable-stayed bridge is a statically indeterminate high-order flexible structure with complex internal force distribution and is very sensitive to changes in various factors affecting construction and use. In particular, the main beam is relatively thin and is elastically supported by the support cable, and the deformation state of the internal force of each part of the structure is very sensitive to the change of the cable force. On the contrary, this is a feature of the cable-stayed bridge structure. By adjusting the voltage of the cable-stayed bridge, the internal strength and deformation of the main girder and even the whole bridge can be artificially changed, so as to maximize the operation of the structure [12-13].

The purpose of the construction control of the cable-stayed bridge is to monitor the structural state in real time during the construction process, and adjust the design parameters and construction process according to the monitoring results, so that the completed project can be as close to the ideal design state as possible. The second is to make the structure reach a reasonable internal strength state during construction, and at the same time to ensure the construction safety during the construction process [14]. The characteristics of rope bridge construction control are:

The strength of the supporting cables must be controlled so that the beams and towers are at their optimum voltage.

The shape of the main beam can be adjusted by the tensile strength of the support cable to meet the design requirements.

2.2. Calculation Theory of Temperature Field

2.2.1. The way of heat transfer

Heat transfer refers to the phenomenon of heat transfer caused by temperature differences. Without doing work, if there is a temperature difference between or between objects, thermal energy must be transferred from a high temperature to a low temperature. The main ways of heat transfer are heat conduction, heat radiation and heat transfer. Heat transfer is a complex process, and these three heat transfer modes generally coexist. During heat transfer, the amount of change in the internal energy of an object is determined by the amount of heat the object receives.

2.2.2. Calculation of temperature field by finite element method

The traditional variational method uses the discrete processing method to solve the temperature field. In the calculation, a tentative function needs to be selected first. However, in the process of selecting the tentative function, the accuracy of the solution of the temperature field is low due to the

influence of multiple factors. First, the problem of solving the temperature field is transformed into the problem of finding the minimum value of the functional by using the variational method, and then the finite element method is used to solve the problem in the space domain and time domain. The flexible element division of the finite element method has good adaptability to various shapes and boundary conditions, and can also handle the problems of non-uniformity and anisotropy. In contrast, the finite element method can achieve more accurate calculations with fewer nodes, so it is often used to deal with problems where the boundaries are natural boundary conditions (such as the third type of boundary conditions for unstable fields).

2.2.3. Semi-empirical and semi-theoretical methods

Among the existing temperature field studies, the semi-empirical and semi-theoretical method is the most widely used method. Semi-theoretical and semi-empirical methods often use the existing measured data, based on the variation law obtained by analyzing the measured temperature field with statistical methods, and combine theoretical analysis to obtain a temperature distribution form that can represent a certain region (or region). In the process of deriving the semi-theoretical and semi-empirical temperature field, it is necessary to simplify the environmental factors to a certain extent. The maximum temperature difference at a certain moment is often used as the control value of the temperature effect in the design, and the changes of solar radiation intensity, atmospheric temperature, etc. are ignored. The influence of external environmental factors such as wind speed changes.

3. Investigation and Research on the Temperature Effect of Railway PC Part Cable-stayed Bridge Based on Long-term Monitoring

3.1. Project Overview

The main research object of this paper is (6+170+95) m prestressed concrete PC part cable-stayed bridge. The bridge site is located in M city, and the bridge site is located in the land-sea interaction plain landform. The terrain of this section is relatively flat and open, with an average altitude of about 1.6m. The region has a humid subtropical monsoon climate with strong solar radiation throughout the year. The M Bridge is a two-tower and two-cable plane prestressed concrete cable-stayed bridge. The main girder adopts a single-box double-chamber straight-web box-shaped section, and the section height adopts the beam bottom line of the quadratic parabola. The beam end of the box girder side span and the middle section of the middle span are both 6.6m high, the support beam is 8m high, the bridge deck width is 12m, and the box width is 10m.

3.2. Measuring Point Layout

In the temperature monitoring of the main bridge of the Dongping Waterway Bridge studied in this paper, the difference fitting method is used to optimize the installation position of the sensor. The difference fitting method is to use the difference method or fitting method to approximate the data of the unknown point through the data of the known measurement points, which can make the sensor after the optimized installation position measure the data that matches the actual situation as much as possible.

In order to measure the temperature distribution of the box girder section as realistically as possible, we have arranged a relatively dense number of temperature sensors on the box girder section, but considering the economy and the requirements of not affecting the construction, it is impossible to select too many sections for temperature monitoring, so only On the main beam, two representative sections at the 1/4 of the main span and the middle of the main span were selected for temperature monitoring.

3.2.1. Test equipment

The JMT-36C sensor can be tested with a multimeter or an automatic temperature test system. The JMT-36C sensor has fast temperature measurement speed and low temperature measurement delay, which is very suitable for long-term and regular temperature monitoring projects.

3.2.2. Data collection

In order to obtain the variation law of the temperature distribution of the concrete box girder with time, it is necessary to continuously measure the temperature of the box girder. However, in order to take into account the storage efficiency of the acquisition equipment, a continuous temperature monitoring method of measuring every half hour is adopted. The measured temperature data is first stored in the temporary memory of the acquisition system, and the temperature data is downloaded, sorted and archived by day by day through wireless remote control through the supporting DSC data receiving software every week.

3.3. Calculation Method of Temperature Stress

The use of finite element software to solve longitudinal temperature stress usually requires the establishment of a solid element model to obtain accurate calculation results, but it will cause a great calculation time and amount of calculation. For the solution of longitudinal temperature self-stress, it can be obtained from the transverse temperature and formula (1).

$$\varphi_1 = \frac{\alpha}{I_x} \iint_S yTdA \tag{1}$$

Where: S represents the section area of the box girder; Ix is the moment of inertia of the box girder section around the x and y axes;

According to the same deformation, we can get:

$$\begin{cases} \alpha \dfrac{T_1 + T_2}{2} = \varepsilon_0 \\ \alpha \dfrac{T_1 + T_2}{h} = \varphi \end{cases} \tag{2}$$

Among them: T1; T2 can be regarded as the temperature of the upper and lower edges of the beam, h is the beam height; ε_0 is the central axis strain; φ is the interface curvature. The treatment of the lateral nonlinear temperature load is the same as that of the vertical one, and finally the vertical temperature load and the lateral temperature load can be superimposed.

4. Analysis and Research on Temperature Effect of Railway PC Part Cable-stayed Bridge Based on Long-term Monitoring

4.1. Temperature Stress Calculation

Using the ANSYS plane strain element model, the transverse temperature stress and longitudinal temperature self-stress at each moment were obtained; using the MIDAS/CIVL beam element model, the longitudinal temperature secondary stress at each unfavorable moment was obtained.

Table 1 shows the equivalent linear temperature value of the nonlinear temperature difference at each moment along the height direction obtained according to formula (2).

Table 1. Equivalent linear temperature difference (°C) along the height direction of the main beam.

Time	Neutral Axis Strain	curvature	T1	T2	T1-T2
1:00	5.35E-06	-1.62E-06	-0.12	1.55	-0.62
5:00	5.02E-06	-5.52E-06	-0.74	3.60	-3.62
10:00	4.55E-06	2.55E-05	3.69	-2.15	8.64
14:00	4.11E-06	4.31E-05	7.15	-9.15	15.17
18:00	3.21E-06	2.61E-05	6.52	-2.66	8.99
20:00	2.75E-06	6.55E-06	1.06	-0.12	1.60

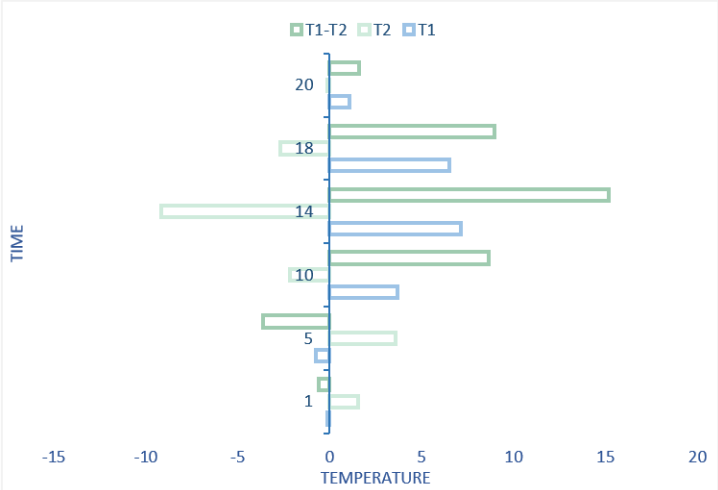


Figure 1. The temperature of the upper and lower edges of the beam at various times.

It can be concluded that the horizontal stress of the box girder section is mainly concentrated in the roof, and the horizontal stress of other parts of the section is very small, as shown in Figure 1. Under the action of positive temperature difference, the outer surface of the top plate is under pressure and the inner wall is in tension, and under the action of negative temperature difference, the outer surface of the top plate is under tension and the inner wall is under pressure. The vertical stress of the box girder section is mainly concentrated in the web, and the vertical stress of other parts of the section is very small. Under the action of positive temperature difference, the outer surface of the web is under pressure and the inner wall is in tension, and under the action of negative temperature difference, the outer surface of the web is under tension and the inner wall is under compression.

4.2. Analysis of the Effect of the Overall Temperature Difference

The change of air temperature has a great influence on the convective heat transfer of concrete on the surface of box girder. Unlike solar radiation, temperature changes not only affect the maximum positive temperature difference during the day, but also affect the negative temperature difference at night. Adjust the temperature change range from 26.5°C~33.3°C to 21.5°C~38.3°C, that is, keep the average temperature unchanged, and increase the temperature difference by 10°C. After the temperature difference increases, the maximum positive temperature difference along the beam height direction increases by 7.4°C at 14:00; the maximum negative temperature difference along the beam height direction increases from 4.1°C to 5.3°C at 6:00, as shown in Figure 2. It can be seen that the increase of air temperature difference has a greater impact on the negative temperature difference of the section than the positive temperature difference of the section. This is because in addition to convective heat transfer and long-wave radiation heat transfer during the day, there is also short-wave radiation, and the impact of short-wave radiation on the positive temperature difference of the cross-section is greater than the former two; while there is no short-wave radiation at night, affecting the cross-section Only convective heat transfer and long-wave radiation are distributed with negative temperature difference. Therefore, the change of air temperature has a greater effect on the negative temperature difference of the section than on the positive temperature difference of the section.

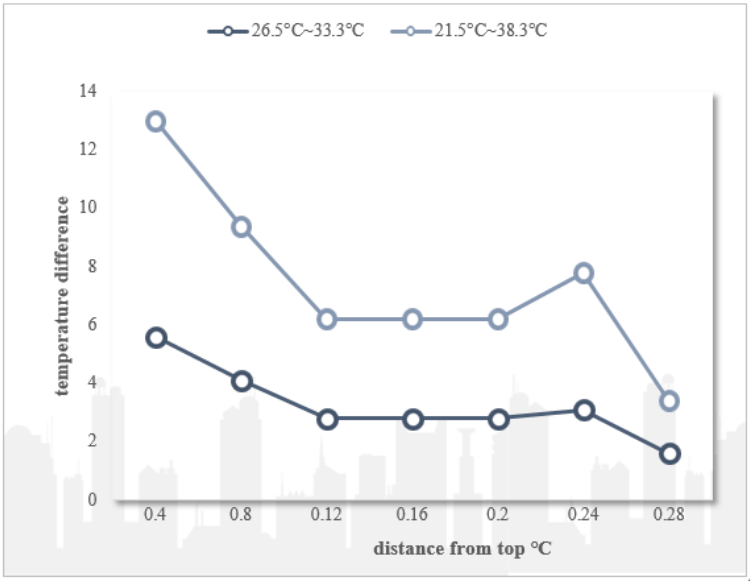


Figure 2. Comparison of the maximum negative temperature difference curves along the beam height.

The difference between the maximum temperature and the minimum temperature of the section has increased, so that the longitudinal self-stress of the temperature at time 6 increases to 6.1MPa, which is very unfavorable for the concrete box girder.

By comparing the analysis of parameters affecting solar radiation and convective heat transfer, we find that solar short-wave radiation is the most important factor causing the temperature difference of the box girder section.

5. Conclusions

Due to subjective and objective reasons such as my knowledge level and limited project time, I believe that there are still many issues that need to be further explored in the process of this article. The following aspects need further research: Due to the limited field conditions, the actual measured temperature data is not accurate enough. For stay cables only the inner surface temperature is tested. If the temperature value of the stay cable can be measured more accurately, the measured data will more objectively reflect the distribution law of the temperature field of the stay cable. The distribution of the temperature field has significant regional characteristics. The temperature fields in this paper are only suitable for similar projects with the characteristics of the bridges in the M area. However, the climates in different regions of my country are very different, and the temperature gradient distribution patterns in different regions need to be based on the actual local temperature field. Testing and theoretical analysis.

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