WEP Warwick Evans Publishing

International Journal of Materials Science and Technology Studies
ISSN: 3006-7693 (Print), ISSN: 3006-3744 (Online) | Volume 3, Number 1, Year 2025
DOI: https://doi.org/10.62051/ijmsts.v3n1.07
Journal homepage: https://wepub.org/index.php/IJMSTS/index

Analysis of Creep Effect of Cable-stayed Bridge Considering Temperature and Humidity Changes

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ABSTRACT

In order to study the influence of environmental temperature and humidity changes on the creep effect of large-span concrete cable-stayed bridges, taking the Mysterious Valley Lancang River Bridge as the background, combined with the measured data of environmental temperature and humidity at the bridge site, and based on the standard model, a creep correction model considering the time-varying of temperature and humidity was established, and compared with the standard model with constant temperature and humidity. The research results indicate that after considering the time-varying effects of temperature and humidity, the displacement and internal forces of the main beam, the displacement and internal forces of the bridge tower, and the cable forces of the inclined cables caused by creep effects will continue to increase. Neglecting the changes in environmental temperature and humidity will underestimate the impact of creep effects. Adopting a modified model that considers the time-varying effects of temperature and humidity can improve the prediction accuracy of long-term creep effects in large-span concrete cable-stayed bridges, which is beneficial for bridge design, construction process monitoring, and later operation and maintenance.

KEYWORDS

Concrete cable-stayed bridge; Environmental temperature; Creep correction model; Creep effect

1. INTRODUCTION

In the booming process of bridge construction in China, concrete cable-stayed bridges have been widely used in the field of bridge engineering due to their excellent spanning ability, scientifically reasonable load-bearing structure, safe and reliable construction process, excellent economy, and good aesthetic effect. As a highly statically indeterminate structure, concrete cable-stayed bridges have complex structural forms, long construction periods, and are extremely sensitive to creep effects[1]. During the construction phase and service period, the deformation and internal forces of bridge structures will continue to change with the development of creep. Therefore, accurately grasping the influence and variation law of creep effect is of indispensable significance for the structural design, construction, and later maintenance of concrete cable-stayed bridges[2-3].

The widely used normative models currently do not take into account the time-varying nature of environmental temperature and humidity. These models all consider the influence of temperature and humidity on the creep coefficient, but only take a fixed value, resulting in significant deviations in their analysis of creep effects. Some scholars have also proposed some improved models[4-9], But it only considers changes in temperature or humidity, failing to take both into account simultaneously. Therefore, this article aims to study the influence of temperature and humidity changes over time on the long-term creep effect of concrete bridges. Based on the CEB-FIP (90) model and referring to other scholars' models and actual data in the structural bridge site area, a creep correction model considering the time-varying nature of temperature and humidity is established. At the same time, a finite element model was established to analyze the creep effect of large-span concrete cable-stayed bridges. The differences in creep effect between the time-varying correction model and the standard model were compared, and the impact of actual environmental temperature and humidity changes over time on structural creep effect was analyzed. This provides a reference for bridge structural design and construction.

2. ESTABLISHMENT OF CREEP MODEL FOR TEMPERATURE AND HUMIDITY CHANGESS

2.1. Actual Measurement of Temperature and Humidity Data in the Bridge Site Area

Install small meteorological stations in the actual bridge area and collect their meteorological data. The testing plan for this experiment is to conduct actual bridge testing on the construction site, and the data collection will be carried out through remote wireless transmission. The layout of on-site sensors is shown in Fig. 1.

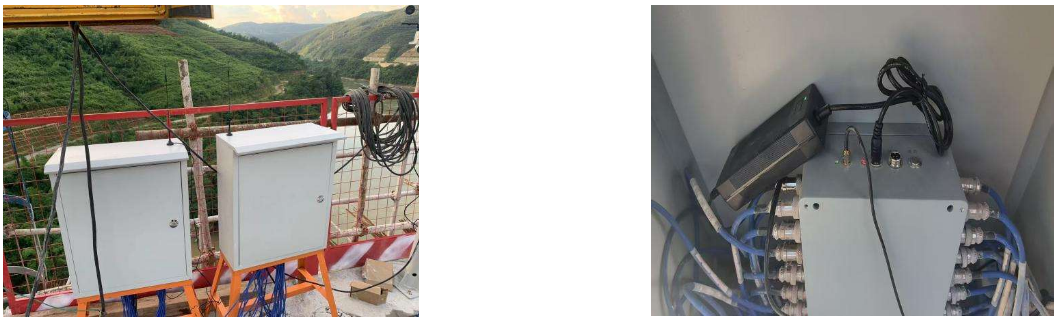


Fig.1 Lancang River Bridge sensor site layout diagram

2.2. Establishment of Correction Model

An accurate and reasonable creep model is crucial for evaluating the performance of bridges. As the CEB-FIP (90) creep model can simultaneously consider environmental temperature and relative humidity, it is currently a widely used creep prediction model. This article is based on the CEB-FIP (90) model and refers to the Lu Zhifang[1]model. By substituting the measured values of temperature and humidity in the bridge site area, a creep correction model considering temperature and humidity changes is established. The specific expression is as follows:

$$\Phi(t,t_0,\theta)=\Phi_0\cdot\beta_c(t-t_0)+\Delta\Phi_{T,trans} \tag{1}$$

$$\Phi_0=\Phi_{HR}\cdot\frac{5.3}{(f_{cm}/f_{cm0})}\cdot\frac{1}{0.1+(t_0/t_1)^{0.2}} \tag{2}$$

$$\Phi_{HR}=\frac{1-H_R/H_{RO}}{0.46(h/h_0)^{1/3}}\cdot{\Phi_T}^{1.2}+\Phi_T \tag{3}$$

$$\Phi_T = \exp\left[0.015\theta / (\theta_0 - 20)\right] \tag{4}$$

$$\beta_c(t - t_0) = \left[\frac{(t - t_0)/t_1}{\beta_{H,T} + (t - t_0)/t_1}\right]^{0.3} \tag{5}$$

$$\beta_{H,T} = \{150\left[1 + (1.2\frac{H_R}{H_{R0}})^{18}\frac{h}{h_0} + 250\right]\} \cdot \beta_T \tag{6}$$

$$H_R\left(t'\right) = b_1 + b_2 t' + b_3 t'^2 \tag{7}$$

$$\beta_T = \exp\left[1500/(273 + \theta/\theta_0 - 5.12\right] \tag{8}$$

$$\Delta\theta_{T,trans} = 0.0004(\theta/\theta_0 - 20)^2 \tag{9}$$

$$\theta\left(t'\right) = a_1 + a_2 t' + a_3 t'^2 \tag{10}$$

$$t' = t - 365\left[t/365\right] \tag{11}$$

In the formulas: $\Phi(t, t_0, \theta)$ is the creep coefficient;$\Phi_0$is the nominal creep coefficient;β_c(t-t_0) is a function of time; $\Delta\ \theta_{T,trans}$ is a function of temperature development over time; H_R is the environmental relative humidity, H_{R0}=100%; θ is the environmental temperature, θ_0=1°C; $t_0$is the age of concrete at the time of loading(d) ;t is the age of concrete at the calculation time,, t_1=1d, t'is the time from the calculation age to January 1 of the year of the calculation age (d), and the value range is0-365d; f_{cm} is the concrete strength, $f_{cm} = 0.8f_{cu,k} + 8$, f_{cm0}=10MPa; $f_{cu,k}$is the standard value of the cubic compressive strength of concrete;his the theoretical thickness of the component, $h_0 = 100$mm; $\theta(t')$ is a function of the time-varying trend of environmental temperature.

3. ENGINEERING OVERVIEW AND FINITE ELEMENT SIMULATION

3.1. Project Overview

The Mysterious Valley Lancang River Bridge is located in Xishuangbanna Autonomous Prefecture, Yunnan Province. It is a double tower double cable plane wide width concrete cable-stayed bridge with a span arrangement of (32+85+300+85+32) meters and a total length of 534 meters. The overall structure is a semi floating system. The main beam is 39.1m wide and adopts two cross-sectional forms: double-sided box and single box four chamber. The center height of the main beam is 3.2m, the side height of the double-sided box is 2.8m, and the side height of the single box four chamber is 3.8m. The bridge deck is 0.3m thick. The bridge is located at longitude 100.79E and latitude 22.04N, with a southwesterly direction of 72°. The annual average temperature in the bridge site area ranges from 25°C to 33°C, and the annual average relative humidity ranges from 72% to 79%. The elevation layout of the bridge deck and the standard cross-section of the main beam are shown in Fig. 2.

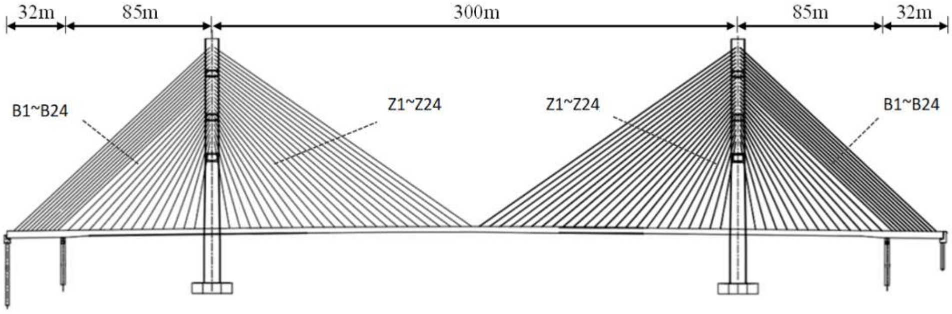


Fig.2 Layout of the bridge deck elevation

3.2. Finite - Element Simulation

A finite element model of the Mysterious Valley Lancang River Bridge was established using the MIDAS program. The inclined cables in the model were simulated using truss elements, while all other elements were simulated using beam elements. There were a total of 618 elements and 809 nodes in the finite element model, as shown in Fig. 3. Analyze the creep effect of the bridge structure during the entire construction process and after ten years of operation, and compare it with the results of the standard model JTG3362-201.

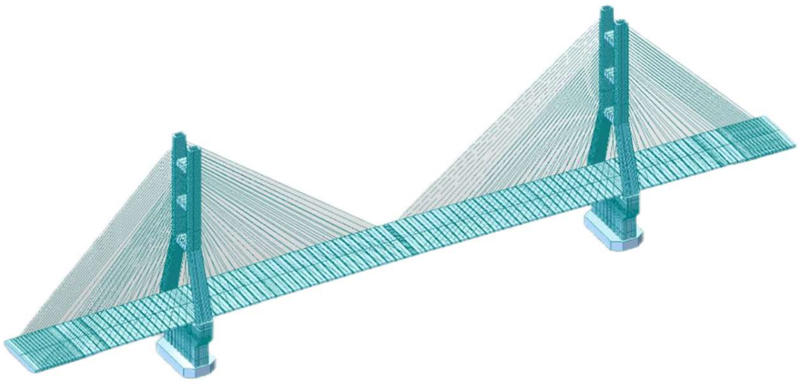
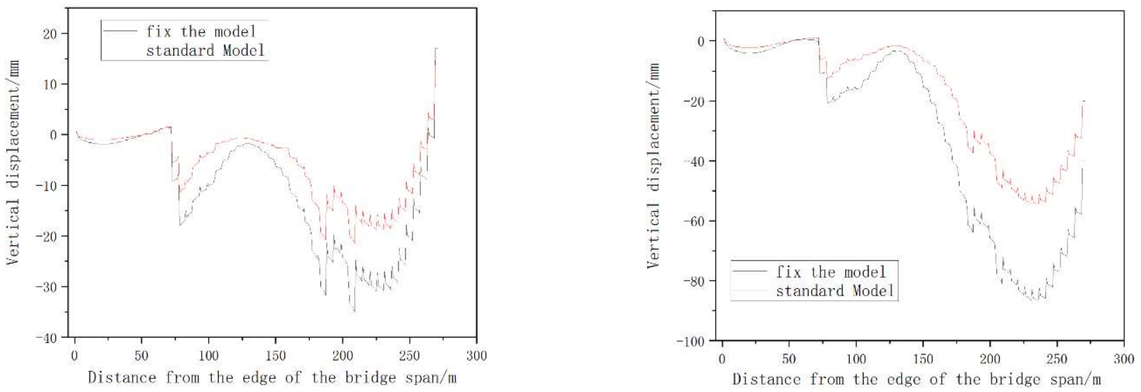


Fig.3 Madis finite element model

4. ANALYSIS OF CREEP EFFECT

4.1. Vertical Displacement of the Main Girder

The vertical cumulative displacements of the main girder of the creep correction model and the code - based model at the bridge - completion stage and ten years after bridge - completion were compared, as shown in Fig. 4.



After the bridge is completed

Ten years after the bridge is completed

Fig.4 Diagram of the vertical displacement of the main beam

(1) After the bridge is completed and ten years after the bridge is completed, the cumulative displacements of the main girder caused by creep in the correction model and the code - based model are symmetric about the mid - point of the main span and show a W - shaped along the bridge - span direction. This indicates that after considering the changes in environmental temperature and humidity, the overall linear characteristics of the creep displacement of the main girder have not changed significantly, but the calculated displacement values have increased.

(2) By comparing the displacements of the main girder before and after the bridge is completed and ten years after the bridge is completed, the cumulative displacement value of the side - span of the correction model after the bridge is completed is - 16mm, which is - 7mm larger than that of the code - based model, with a change range of about 78%. The maximum cumulative displacement value of the middle - span of the correction model is - 34mm, which is - 12mm larger than that of the code - based model, with a change range of about 54%. Ten years after the bridge is completed, the maximum cumulative displacement value of the side - span of the correction model is - 20mm, which is an increase of - 10mm compared with the code - based model, with an increase range of 100%. The maximum cumulative displacement value at the mid - point of the middle - span of the correction model is - 86mm, which is an increase of - 31mm compared with the code - based model, with an increase range of 56%. The creep effect has a relatively large impact on the displacement of the side - span main girder, but the absolute value is small, while the displacement increase range and change value of the middle - span main girder are both large. This indicates that under the long - term action of the concrete creep effect, the displacement of the middle - span main girder of the long - span cable - stayed bridge will continue to deflect downward.

(3) From the above analysis, it can be seen that after considering the environmental temperature and humidity change effect, the displacements of the main span and side - span caused by the creep effect have increased to varying degrees. Ignoring the creep effect caused by the actual changes in environmental temperature and humidity will greatly underestimate the downward deflection value of the middle - span main girder.

4.2. Analysis of Stay - Cable Force

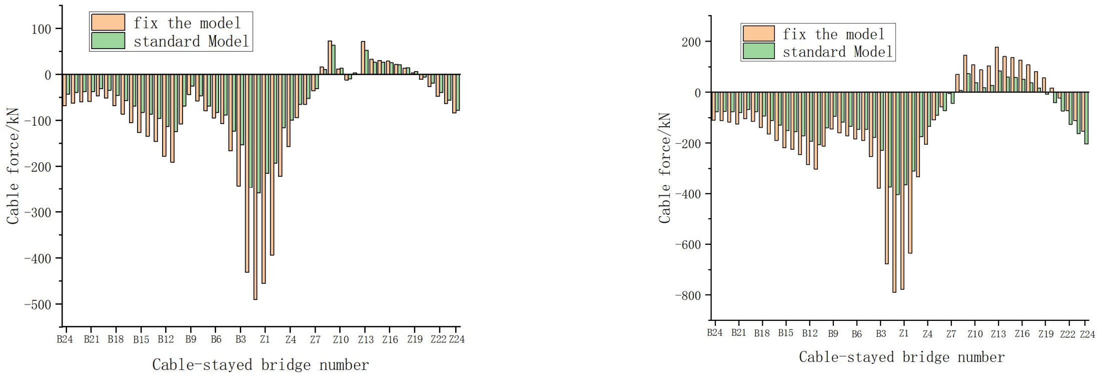
Fig. 5 shows the stay - cable force values of the correction model and the code - based model when the creep is completed after the bridge is completed and ten years after the bridge is completed.
It can be seen from Fig. 5:

(1) The change laws of the stay - cable forces caused by the creep effect in the correction model and the code - based model are roughly the same. The cable forces basically increase gradually from the

side - span of the bridge to the bridge tower, and the cable forces are negative. The cable forces decrease from the bridge tower to the mid - span side, and the cable forces caused by the creep effect are positive at the middle cables Z7-Z16. The cable force values Z1 and B1 at the bridge tower reach the maximum. The reason is that the stay cables at the bridge tower are short cables, and the vertical displacement caused by creep at the bridge tower is relatively large, resulting in a greater cable force required for the short cables at the bridge tower.

(2) When the second - stage pavement is completed, the maximum cable force value of the correction model is - 490kN, which is an increase of 232kN compared with - 258kN of the code - based model, with an increase range of 89%. As time goes by, due to the increasing influence of creep and environmental temperature and humidity changes on the bridge, the stay - cable forces continue to increase, and the difference in cable forces between the correction model considering temperature and humidity changes and the code - based model with constant temperature and humidity becomes more and more obvious. When the ten - year shrinkage and creep are completed, the maximum cable force value of the correction model is 790kN, which is an increase of 387kN compared with 403kN of the code - based model, with an increase range of 96%, which is about 1.6 times the increase compared with the initial stage of bridge completion.

(3) In summary, the cable forces caused by the creep effect are negative near the side - span and the bridge tower, which can reduce the stress burden of the bridge under the overall working condition, while the cable forces of the cables Z7-Z16 are positive, which will increase the stress of the bridge stay cables under the overall working condition. The difference in cable forces between the correction model considering temperature and humidity changes and the code - based model with constant temperature and humidity continues to increase with time. For the side cables and middle cables near the bridge tower, the correction model can reduce the stress burden of the bridge to a greater extent. For the middle cables Z7-Z16, it is necessary to improve their strength and take precautions.



After the bridge is completed

Ten years after the bridge is completed

Fig.5 The second phase of pavement and ten-year shrinkage creep to complete the cable-stayed cable diagram

5. CONCLUSION

In this paper, through the study of the measured values of environmental temperature and humidity in the bridge site area of Yunnan, a creep correction model for environmental temperature and humidity changes that is suitable for the bridge site area was established. Taking the temperature and humidity change process of each construction beam section of Shenmi Valley Bridge as the environmental background, a finite element model was established to analyze the creep effect of the bridge and compare it with the results of the standard model. The conclusions are as follows:

(1) The analysis of the creep effect on the bridge displacement shows that after considering the environmental temperature and humidity changes, the linear characteristics of the main beam and the top of the tower in the completed - bridge state remain unchanged, and the law of change over time is roughly the same as that of the standard model, but the displacement values all increase to varying degrees. After ten years of creep completion, the maximum vertical displacement of the main beam and the deviation of the top of the tower increased by 56% and 31% respectively. The greater the amplitude of environmental temperature and humidity changes, the more significant the effect of the creep effect on increasing the bridge displacement value. For areas with high annual average temperature and humidity and large amplitude of change, ignoring the creep effect caused by environmental temperature and humidity changes will underestimate the actual displacement value of the bridge.

(2) The change laws of the stay - cable forces caused by the creep effect in the correction model and the standard model are roughly the same. The cable force value at the bridge tower is the largest and gradually decreases to both sides of the mid - span of the side - span, and the cable forces at the middle cables Z7-Z16 are positive. As the influence of the creep effect and environmental temperature and humidity changes on the bridge continues to increase, the cable forces of the stay - cables continue to increase. Ten years after the bridge is completed, the cable force of the correction model is approximately 96% greater than that of the standard model, which is about 1.6 times the increase compared to the initial stage of bridge completion. In summary, the cable forces caused by the creep effect are negative near the side - span and the bridge tower, and the cable forces of the cables Z7-Z16 are positive. For the side - cables and middle - cables near the bridge tower, the correction model can reduce the stress burden of the bridge to a greater extent. When using the correction model for the middle - cables Z7-Z16, it is necessary to improve their strength and take preventive measures.

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