International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:4, No:10, 2010

Measurement and Analysis of Temperature Effects on Box Girders of Continuous Rigid Frame Bridges

Bugao Wang, Weifeng Wang, and Xianwei Zeng

***Abstract*—**Researches on the general rules of temperature field changing and their effects on the bridge in construction are necessary. This paper investigated the rules of temperature field changing and its effects on bridge using onsite measurement and computational analysis. Guanyinsha Bridge was used as a case study in this research. The temperature field was simulated in analyses. The effects of certain boundary conditions such as sun radiance, wind speed, and model parameters such as heat factor and specific heat on temperature field are investigated. Recommended values for these parameters are proposed. The simulated temperature field matches the measured observations with high accuracy. At the same time, the stresses and deflections of the bridge computed with the simulated temperature field matches measured values too. As a conclusion, the temperature effect analysis of reinforced concrete box girder can be conducted directly based on the reliable weather data of the concerned area.

***Keywords*—**continuous rigid frame bridge, temperature effect analysis, temperature field, temperature field simulation

I. INTRODUCTION

ONLY the most adverse temperature field for a region is defined according to the current bridge design codes, the change rules of temperature field of reinforced concrete box girder have not yet been well studied [1]. In fact, the temperature field of the box girder is not always at the most adverse situation in the most time of a year. Therefore the temperature field variation cannot be considered solely by using the design codes. As the construction cycle of large span bridges is long enough to have seasonal changes and the effects of temperature field change on the structure are very complicated, researches of change rule of temperature field and temperature effect on the structure are obviously necessary[2].

II. OBJECTIVE

This paper investigates the rules of temperature field changing and its effects on bridge structures using onsite measurement and computational analysis. The onsite measurement of Guanyinsha Bridge is used as a case study in this research. Computational analysis is also implemented to compare with observation of the bridge. The general temperature field distribution rule for Zhujiang Region in the seasons of fall and winter and the temperature effects on large span continuous rigid frame bridges during construction are also presented.

Bugao Wang is a master student at the School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, 510640, China (e-mail: wbg707@qq.com).
Weifeng Wang is a professor with the School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, 510640, China (phone:+86.20.87111590; fax:+86.20.87114460; e-mail: ctwfwang@scut.edu.cn).
Xianwei Zeng is an associate professor with School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, 510640, China (e-mail: zengxw@scut.edu.cn).

III. TEMPERATURE MEASUREMENTS

A. Arrangement Plan of Temperature and Stress Measurement

Guanyinsha Bridge is a large span bridge between Guangzhou (Xin Zhou) and Panyu (Tan Wei) of JingZhu North Express Way in Guangdong Province, China. The structure form of main bridge is prestressed concrete continuous rigid frame and the span combination is 65m-120m-120m-65m. During the construction of Guanyinsha Bridge, two temperature measuring sections are arranged at No.3 T shape part of right longitudinal direction with total 40 measuring points. 9 measuring points are arranged at the beam web near 1# segment from the bottom to top of the beam, 7 measuring points are arranged at the beam web near 6# segment along the beam height. Nickel chrome – nickel silicon thermocouples are used to measure the temperature in the concrete, mercury thermometers are used to measure the temperature in and out of the box girder[3,4] as shown in Fig. 1to3.

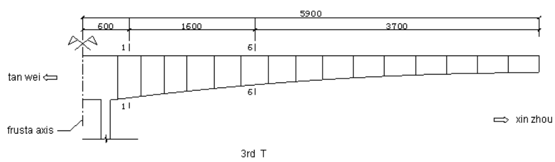

Fig. 1 Section position of temperature and stress measurement

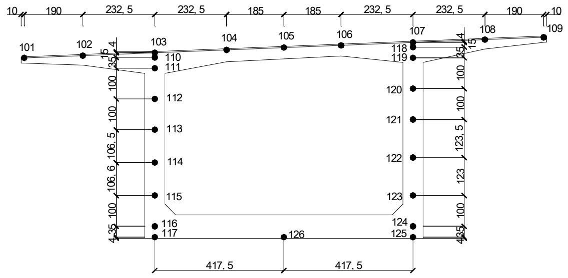

Fig. 2 Arrangement plan of temperature measurement in section no.1

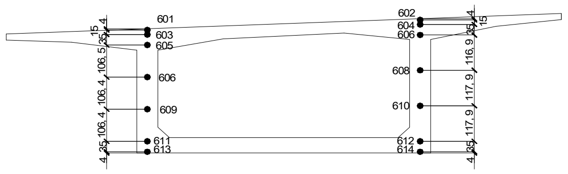

Fig. 3 Arrangement plan of temperature measurement in section no.6

B. Analysis of Temperature Measuring Results

In order to reduce the measuring error and for the convenience of data processing, the average value of measuring points 102, 108 and 109 of Section 1 are denoted as aver1, aver 2 is the average value of measuring points 104, 405 and 106. The temperature fields in three typical weather conditions, i.e. sunny day, temperature lower day after cold snap and temperature higher day, are measured. For simplification, in this paper, only the temperature fields at sunny day are presented as shown in Fig. 4 to 10.

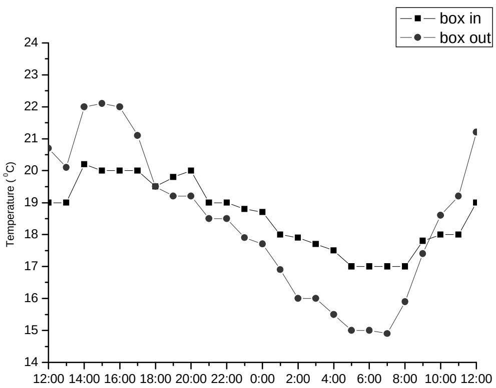

Fig. 4 Measured air temperature vs time(sunny)

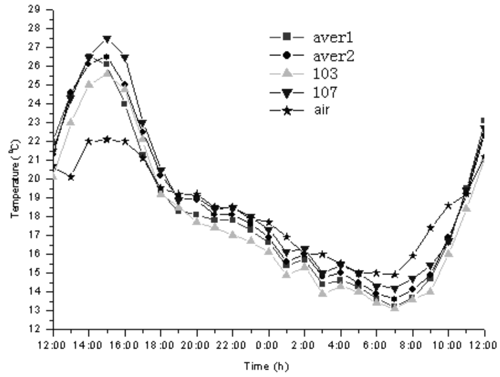

Fig. 5 Measured bridge deck temperature vs time(sunny)

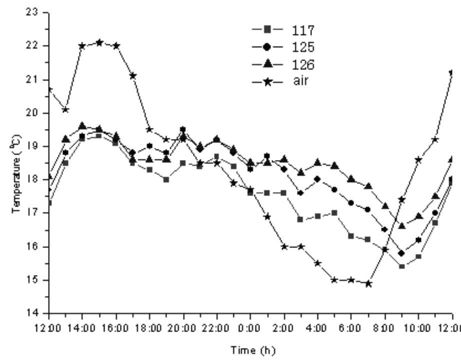

Fig. 6 Measured bottom slab temperature vs time(sunny)

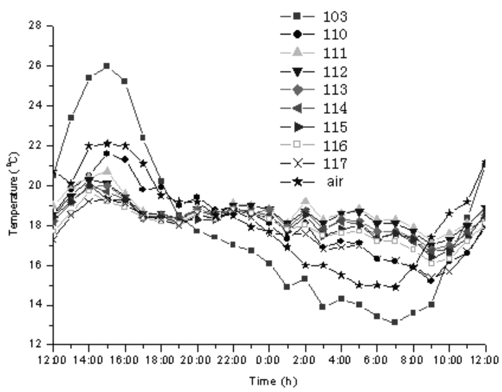

Fig. 7 Measured temperature vs time in east web of s1 (sunny)

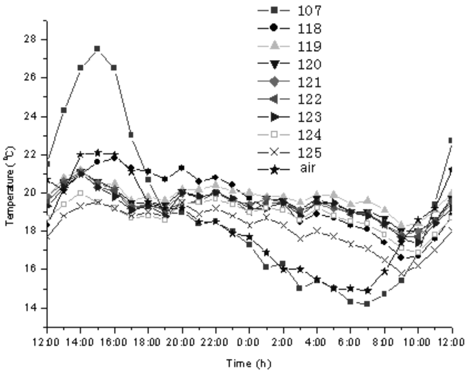

Fig. 8 Measured temperature vs time in east web of s1 (sunny)

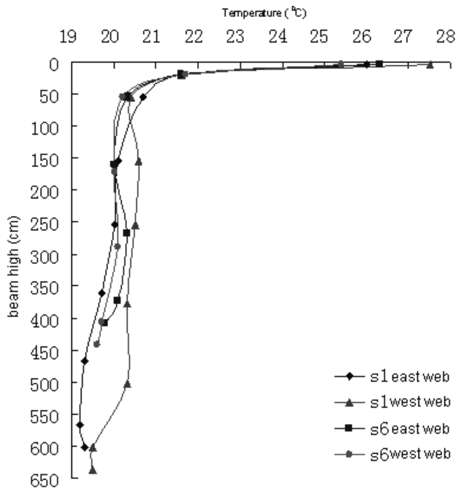

Fig. 9 Thermal gradient in web (15:00, sunny, air: 22.1℃)

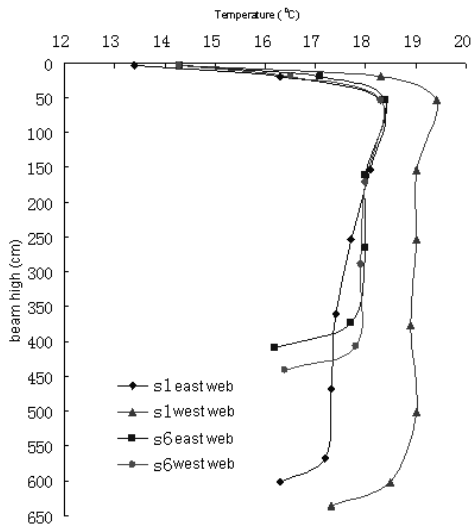

Fig. 10 Thermal gradient in web (6:00, Dec. 6th, sunny, air: 15.0℃)

IV. Compunational Analysis Of Temperature Field

A. Assumptions

Three basic assumptions were determined before computational analysis [2]:

1) The effect of reinforcement on concrete heat exchange is not considered. The concrete is assumed homogeneous and isotropic.
2) The physical parameters of concrete are assumed independent on the temperature.
3) The initial temperature in the box girder is assumed as the same.

B. Temperature Field Simulation

The finite element analysis package, ANSYS, was used in this study. The instant temperature field of the structure is simulated with the heat analysis function of ANSYS. The convection heat exchange between box girder and air is simulated with the convection of the boundary condition in the heat analysis of ANSYS, and the radiant heat exchange between the structure and air is simulation with the radiant between node and plane in the heat analysis. The sun radiant, dispersion radiant and earth surface reflect radiant are simulated with the plane load in the heat analysis of ANSYS[5].

The wind speed and sun radian intension are achieved from the Guangzhou Panyu Weather Bureau, which install an auto collection station about 3km distance from the bridge site to collect the meteorologic data such as air temperature, wind speed, humidity, visibility and the cloud height. It should be noted that the anemoscope is installed with the height about 2m. As the box girder of No. 3 T shape part of Guanyinsha Bridge is about 20.5m to 27.2m high, the wind speed should be modified according to the height [5].

Take the sunny day as the instance and the temperature distribution measured at 6:00 as the initial temperature field, the sun radiant intension is determined according to the collected value of the local Weather Bureau, the wind speed outside of the box girder is defined as 4 times of the measured value, the wind speed in the box girder take 1m/s, the other parameters is adopted as follows: heat exchange factor λ 3.5w/(m·K), specific heat c 960J/(kg·K), density ρ 2400kg/m^3, absorbing factor αb 0.65. The temperature distribution of box girder calculated with ANSYS is shown in Fig. 11 and 12.

C. Effect of Calculation Parameters

The temperature field simulation is based on the heat exchange differential equations and the corresponding solution conditions, for which many parameters should be treated. These parameters affect the temperature distribution to the different extent[5,6]. In this paper, the qualitative analysis of the effect extents of the different parameters on the temperature field is conducted.

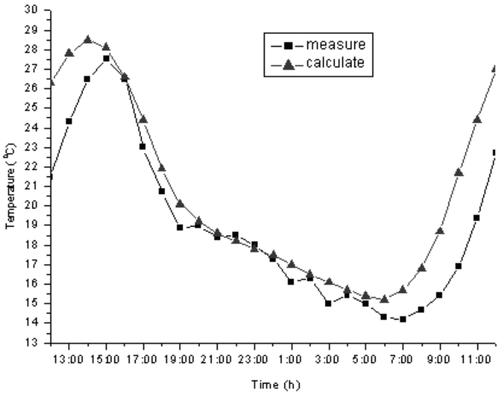

Fig. 11 Comparison of measured and calculated deck temperature

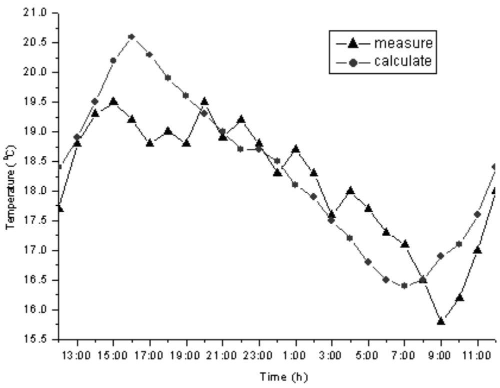

Fig. 12 Comparison of measured and calculated soleplate temperature

D. *Wind Speed*

The effect of wind speed on the bridge temperature field is conducted with the convection heat exchange factor. As different wind speed has the different convection factor, different convection factor is applied to simulate the convection heat exchange between the structure and environment to the different levels[7]. For analyzing the effect of different wind speed on temperature field, the following assumptions are conducted in this paper: when sunny day is considered, the radiant boundary condition is adopted as the measured sun radiant intention by the Weather Bureau, the convection factor of the outer surface is calculated by timing 2, 3 or 4 with the measured wind speed, the other parameters are the same. The calculation results are shown in Fig. 13 and 14.

According to Fig. 13 and 14, the maximum difference between the calculation results of 2 times wind speed and 4 times wind speed is more than 10℃. It means that the effect of wind speed on temperature field is significant. Consequently, one of the factors to affect the simulation precision is wind speed at the temperature field simulation calculation.

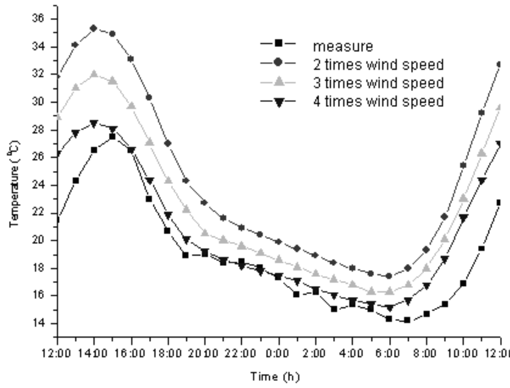

Fig. 13 Comparison of measured and calculated deck temperature

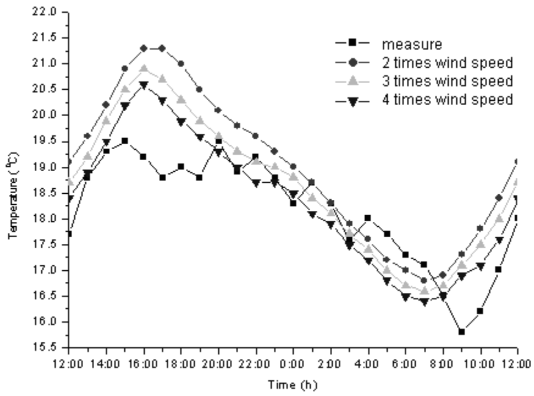

Fig. 14 Comparison of measured and calculated soleplate temperature

E. *Heat Exchange Factor*

Larger heat exchange factors are desired to get better heat exchange property and shorter time to balance the temperatures. The heat exchange factor values in the literatures[5,7] are quite different. As this factor is difficult to define, the effect of the different values on temperature field is discussed in this paper. The wind speed outside of the box girder is magnified 4 times, and the other parameters are the same with the above section except the heat exchange factor. The results are shown in Fig. 15 and 16.

From Fig. 15 and 16, less the heat exchange factor λ, larger are the temperature peaks of measuring points and smaller are the small values. It means that the heat exchange factor is less, the uniformity of the concrete temperature distribution is adverse. That is the nonlinearity of temperature grads is more distinct, so larger temperature stress is induced. According to the figures, they match very well if λ is 3.5. As a result, for prestressed concrete box girder in Zhu-Jiang area the concrete heat exchange factor λ should be not less than 3.5.

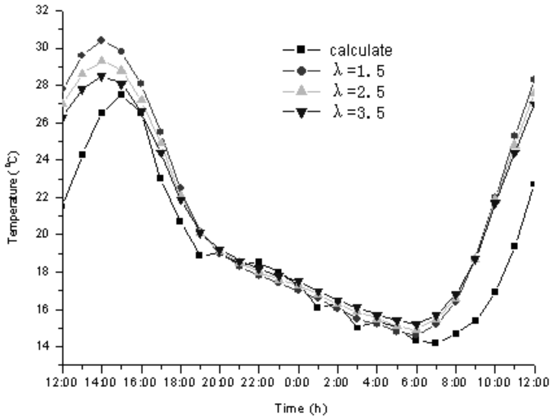

Fig. 15 Comparison of measured and calculated deck temperature

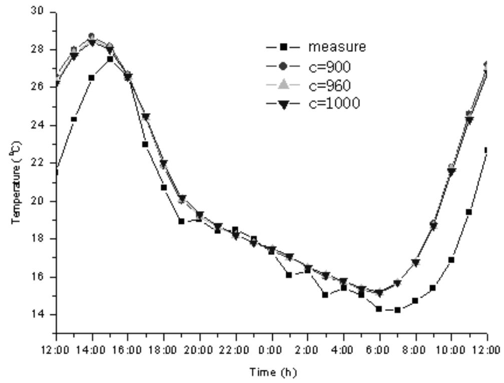

Fig. 17 Comparison of measured and calculated deck temperature

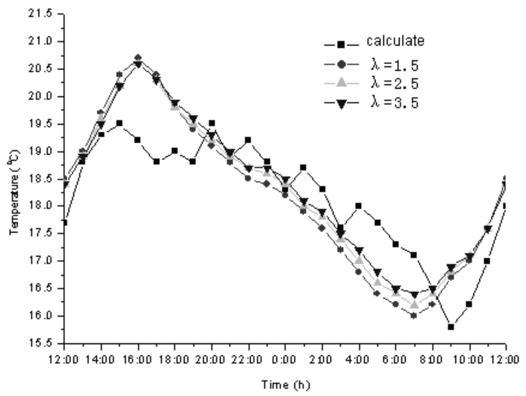

Fig. 16 Comparison of measured and calculated soleplate temperature

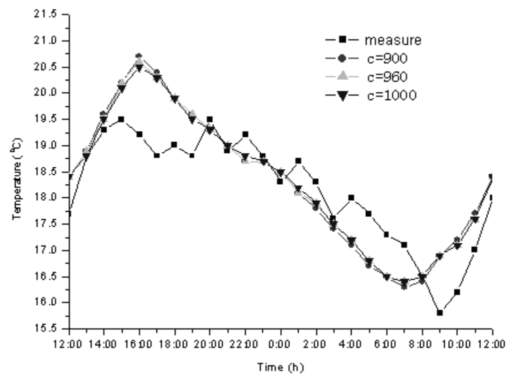

Fig. 18 Comparison of measured and calculated bottom slab temperature

F. Specific Heat

Specific heat of concrete cannot make consistent in the literatures[7,8]. As this parameter is difficult to measure, the reasonable value range is discussed in this paper. In this section the other parameters are the same with the above section except specific heat.

As shown in Fig. 17 and 18, the calculation results are similar when specific heat is 900, 960 and 1000J/(kg·K) respectively. Consequently, the value of specific heat can be from 900 to 1000J/(kg·K) for the prestressed concrete box girder of Zhu-Jian Area in China.

V. Analysis Of Temperature Effects

The instantaneous temperature field of the structure is simulated with the heat analysis function of ANSYS. The calculated results are compared with the measured results.

A. Comparison between the Measured Stress and Calculated Stress

Because there are many effect factors for stress except the temperature effect, the detailed effect will be studied further[5,8]. In addition, measured stress is delayed by the calculated stress since the change of temperature to stress need time. Assume that the effect extent of undefined factors on longitudinal stresses of top and bottom fibers are equivalent, the comparison of the stress differences between top and bottom fibers of top and bottom plates is rational. The comparison results are shown in Fig. 19.

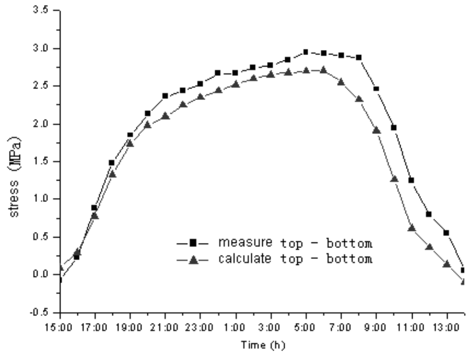

Fig. 19 Comparison of measured and calculated stress difference(sunny)

B. Comparison of Measure Deflection and Calculated Deflection

The temperature deflection comparison of measured and calculated values at the forepart of 15# and 14# beams at the moment of 15# construction is shown in Fig. 20 and 21. The downwards deflection is defined as positive.

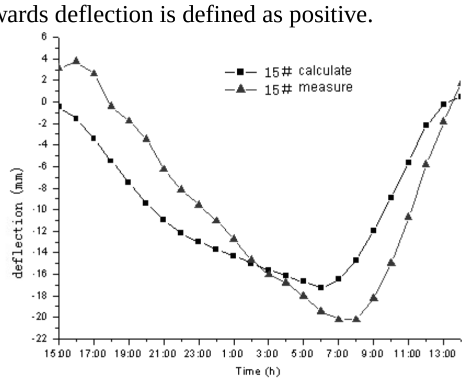

Fig. 20 Comparison of measured and calculated deflection (sunny)

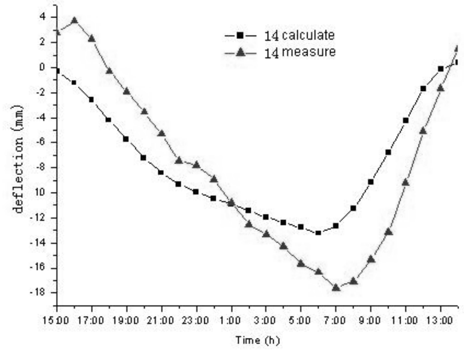

Fig. 21 Comparison of measured and calculated deflection (sunny)

As shown in Fig. 20 and 21, the change rules of calculated and measured temperature deflection are alike, but, the measured one is delayed than the calculated one. The reason of larger deviation of measured deflection includes the main girder additional deflection induced by the rotation of pier and girder fix joint, which is not considered in the calculated model. In the sunny morning, additional upwards deflection of the main girder is produced by the rotation of pier and girder fix joint due to sun radiant. As a result, the measured deflection, which is the sum of negative additional deflection and bending deflection, is smaller than the calculated one in the morning. As vary of the sun height angle, the additional deflection of the main girder changes from upwards to downwards, then the measured deflection is larger than the calculated one. Therefore, due to the additional deflection of the main girder, the measured deflection is smaller than the calculated one in the morning and larger in the afternoon. The flexible pier must be considered in the calculated model of temperature field of the structure. During the construction monitoring, the definition of the mode elevation for the different temperature fields should be based on the calculated results and consider the delay of temperature effect.

VI. Conclusion

In this paper the simulation method for temperature field of concrete box girder, which is based on the observed data from local Weather Bureau, is proposed and the effect of model parameters on the calculated results are investigated. The following conclusions could be drawn from the research results:

1) When the concrete parameters are defined, the precision temperature field of concrete box girder is simulated according to the data from local Weather Bureau. This can reduce the measuring work and make the design method of concrete box girder perfect.
2) Wind speed affects the temperature field of box girder significantly. The wind speed should be modified according to the height. The distribution of wind speed along the height should be studied further. For the box girders of Zhu Jiang Area, the concrete heat exchange factor should be not less than 3.5. The concrete specific heat should be in the range from 900 to 1000 J/(kg•K).
3) Temperature affects the stress and deflection of box girder of prestressed concrete continuous rigid frame bridge dramatically. Therefore, the temperature effect should be considered for the design, construction and construction monitoring and be treated very well. For construction monitoring, the mode elevation should be based on the calculated results and consider the temperature effect delay.

References

[1] C. Chen, "Analysis of Temperature Influence on Long-span Prestress Concrete Cable-stayed Bridge Construction Control," *Journal of Highway And Transportation Research And Development*, vol. 19, no. 6, Dec. 2002.

[2] W. H. Dilger, A. Ghali, M. Chan, M. S. Cheung, and M. A. Maes, "Temperatures stresses in composite box girder bridges," *Journal of Structural Engineering, ASCE*, vol. 109, no. 6, pp.1460-1478, Jun. 1983.

[3] K. Hu, “Measurement and Analysis of Temperature Fields and Effects on Flexible Pier,” *Journal of Shanghai Tiedao University*, 1982(3).

[4] Y. Ge, D. Zhai, and G. Zhang, “Temperature Gradient Test and Research of RC Cable-Stayed Bridges,” *Chinese Journal of Highway And Transportation*, vol. 9, no. 2, Jun. 1996.

[5] J. C. Reynolds, and J. H. Emanuel, “Thermal stresses and movements in bridges,” *Journal of the Structural Division, ASCE*, vol. 100, no. 1, pp. 63-78, Jan. 1974.

[6] S. Moorty, and C. W. Roeder, “Temperature dependent bridge movement,” *Journal of Structural Division, ASCE*, vol. 118, no. 4, pp. 1090-1105, 1992.

[7] F. Kehlbeck, *Effect of Solar Radiation on Bridge Structure*. (LIU Xing-Fa, et al transl.), Beijing : Chinese Railway Publishing Company, 1981.

[8] M. M. Eibadry, and A. Ghali, “Temperature variations in concrete bridges,” *Journal of Structural Engineering, ASCE*, vol. 109, no. 10, pp. 2355-2374, Oct. 1983.