ANALYSIS OF THE EFFECT OF AMBIENT TEMPERATURE ON THE BEHAVIOR OF A BOXED ARCH RIB

BORONG WANG[1], JING GAO[1*], CHENG LUO, JINFENG LI

[1]Department of Civil Engineering, Xiamen University, Xiamen 361005, China
*E-mail: *gaojing@xmu.edu.cn*

Temperature variations are generally caused movements in bridge structures. It is important to correctly understand the operational performance of bridge elements affected by temperature in real time. This case study deals with a steel arch bridge in the island of Xiamen, China, equipped with a monitoring system. Preliminary results obtained using data stored in a long period under different climate and load conditions are presented. The sampling data of the strain data of the health monitoring system is 100Hz, which can obtain a large amount of strain data, but the external factors (noise) will have more serious interference corresponding to the variable data record. In order to reduce the error caused by noise interference, the data needs to be denoised before data analysis. By using wavelet denoising method to preprocess the 1/2 arch rib strain data in the monitoring system and the temperature data of the environment, the correlation analysis between the single arch rib strain measurement point and temperature are carried out to analyze the correlation between arch rib strain and temperature. Then, through the MATLAB programming calculation, the temperature and the correlation coefficient of each strain point are obtained. The results show that there is a significant linear relationship between temperature and arch rib strain. The significant linear relationship between the strain points of each arch rib can reduce the data processing by which the correlation model was established. It is further analyzed how the results should be used for a reliable bridge management.

Keywords: Boxed Arch rib, Ambient temperature, Behavior, Correlation.

1 Introduction

The bridge structure will be affected by factors such as ambient temperature, sunshine radiation and boundary air flow, which will produce uneven sunshine temperature field (Liu *et al.* 2017). Engineering practice and theoretical analysis show that the resulting temperature stress even exceeds the live load stress, and the temperature stress will have a large periodic fluctuation during the temperature difference between day and night and the climate change throughout the year. Periodic changes in temperature stress and excessive values result in damage, cracks, and even damage to the components, causing bridge accidents (Dong *et al.* 2017, Zeng *et al.* 2010 and Liu *et al.* 2018). Therefore, it is of practical significance to explore the influence of temperature on the stress of the bridge structure.

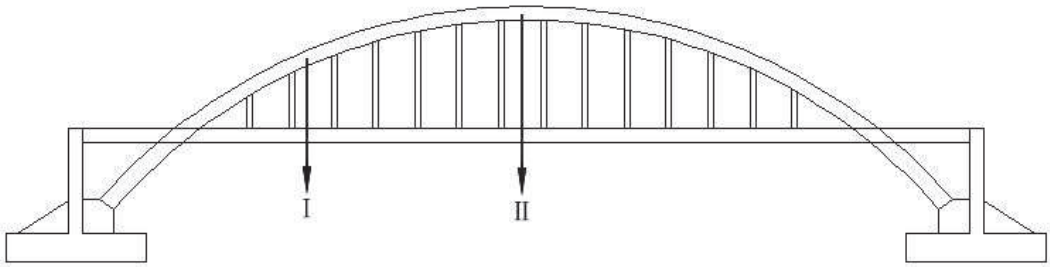
In this paper, Xiamen Tianyuan Bridge is taken as the research object, and the temperature and strain of steel box girder and arch rib are monitored for a long time. By using wavelet denoising method to preprocess data, and the processed data is statistically analyzed by means of hypothesis testing. The relationship between temperature and rib strain is mainly studied. It is further analyzed how the results should be used for a reliable bridge management.

Proceedings of the 17th International Symposium on Tubular Structures.
Editors: X.D. Qian and Y.S. Choo

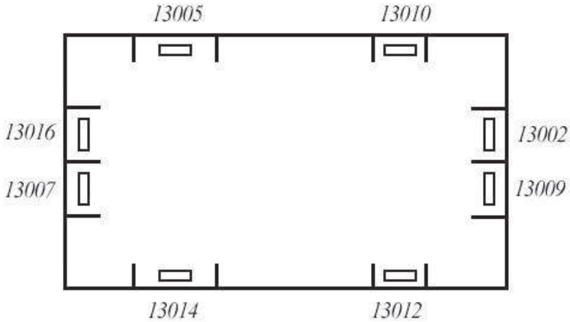
Published by Research Publishing, Singapore.
ISBN: 978-981-11-0745-0; doi:10.3850/978-981-11-0745-0_022-cd

2 Observation section and measuring point arrangement of Tianyuan Bridge

Tianyuan Bridge is a half-through steel arch bridge with a span of 120m and width of 32m.The deck is connected with the arch rib by 14 rigid suspenders with a spacing of 6m. At the intersection, the deck girder is seated at two short spandrel piers over the arch rib. Another two piers support the deck girder at the two ends. Fig. 1 shows the observation section and strain measuring point arrangement of the arch rib of Tianyuan Bridge. The observation section of the rib is a 1/4 span and a 1/2 section.



a)Observation section of Tianyuan Bridge



b)Strain measurement point arrangement

Figure. 1 Observation section and strain point arrangement of Tianyuan Bridge

3 Long-term health monitoring data preprocessing

The strain acquisition frequency of the Tianyuan Bridge Health Monitoring System is 100HZ, that is, a single measuring point produces 8,640,000 raw strain data per day. The original strain data is inevitably affected by the operational environment factors. The data is analyzed by strain, and the strain changes within the adjacent 10min is not large. Therefore, the average time interval is 10min, and the average value is used to represent the strain value.The strain time history mainly reflects two types of load information at different time scales: one is the temperature load signal, and the other is the live load information based on the vehicle.

The temperature effect component in the original strain data has a slow change characteristic with respect to the live load effect component (Li *et al.* 2015). In order to peel off the strain generated by the vehicle load, the original strain data is processed by Fourier transform and wavelet noise reduction (Li *et al.* 2019).The original strain data is transformed from the time domain signal into the frequency domain by Fourier transform, and then the frequency components of the data are obtained; the wavelet transform can decompose the data into different time scales to obtain signal components at different frequencies (Liang *et al.* 2019).

3.1 *Fourier transform of temperature and strain monitoring data*

The temperature and strain data have different ranges of values. Before the Fourier transform, the data needs to be standardized, and the function of the matlab is used to process the data so that the processed data is in a uniform range. The results of the Fourier transform of the atmospheric temperature and the ribbed strain of 13005 in the first half of January 2017 are shown in Fig. 2 and Fig. 3, respectively.

It can be seen from Fig. 2 that the FFT spectrum of the temperature data has two main frequencies, and the corresponding periods are a 24h period with a large amplitude and a 12h period with a small amplitude. As can be seen from Fig. 3, the two main frequencies of the strain data FFT spectrum, around the 24h, 12h period, have approximately the same period as the temperature data. Therefore, from the frequency domain composition, the temperature change has a strong correlation with the strain change. The amplitude of the 24h and 12h periodic components is much larger than the amplitude of other periodic components, which explains the strain of the rib of the Tianyuan Bridge to some extent. A large part of the composition is caused by temperature changes.

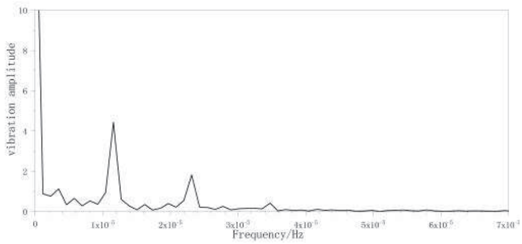


Figure. 2 Temperature data FFT spectrum

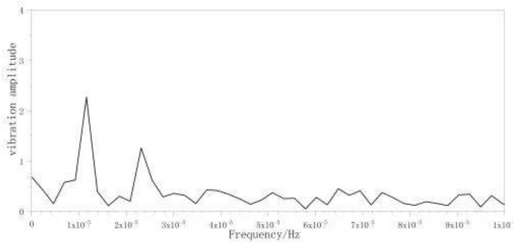
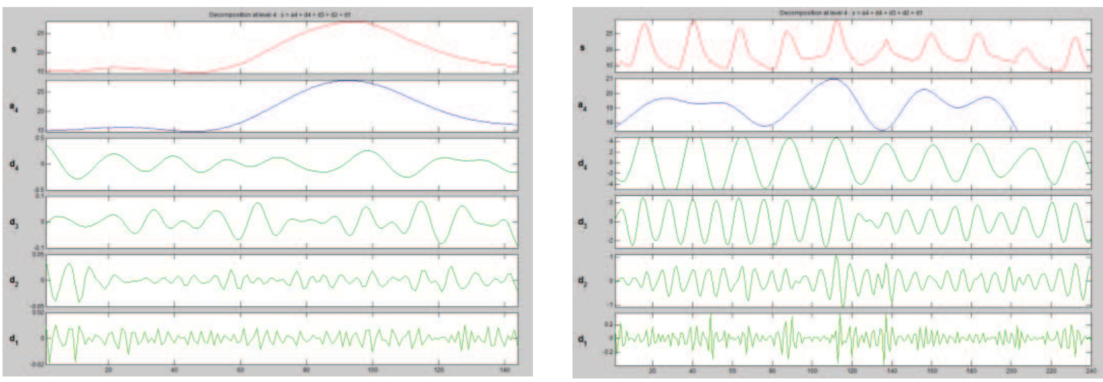


Figure. 3 Strain data FFT spectrum

3.2 *Wavelet transform of temperature and strain monitoring data*

This section will use wavelet transform to further study and analyze the temperature and strain monitoring data.The measured temperature and strain data were decomposed using the db30 wavelet in Matlab software.The temperature and arch rib measurement point of the 13005 strain wavelet transform on January 1, 2017 is shown in Fig. 4.



a)temperature b)strain

Figure. 4 Decomposition of measured data by wavelet transform

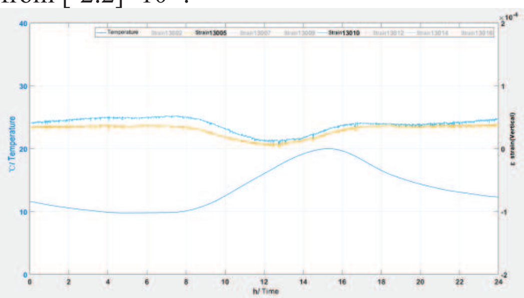
It can be seen from Fig. 4 that $s=a_1+d_4+d_3+d_2+d_1$, s is the original curve, a4 is the approximate signal of the original signal, and the d_4~d_1 layers are the signal components of different frequencies, respectively, and the d4 layer signal and d_3 The periods of the layer signals are 24h and 12h, respectively (Zhang *et al.* 2011). For the strain data, the d_4 and d_3 layer signals are mainly caused by the daily temperature change; the d_2 and d_1 layers have higher signal frequencies, which are mainly caused by high-frequency random loads and noises such as vehicles .Therefore, the d4 layer signal after wavelet transform can effectively eliminate the influence of vehicle load (Sun *et al.* 2019).

4 Analysis of the correlation between Air temperature and Longitudinal strain monitoring data

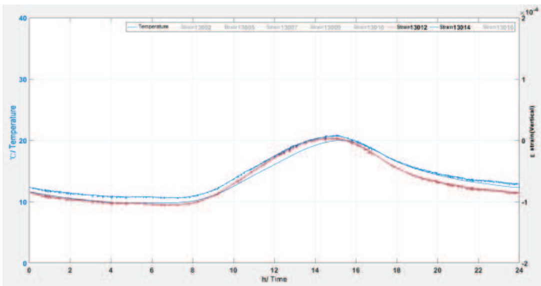
Through the Fourier transform and the wavelet transform, the strain caused by the vehicle load is separated from the original strain data, and only the strain caused by the atmospheric temperature is retained. This section is based on the processed data to study the effect of atmospheric temperature on the longitudinal strain of 1/2 arch ribs; and the correlation between 1/2 arch rib strain points.

4.1 *Arch rib longitudinal strains measurement points and air temperature correlation analysis*

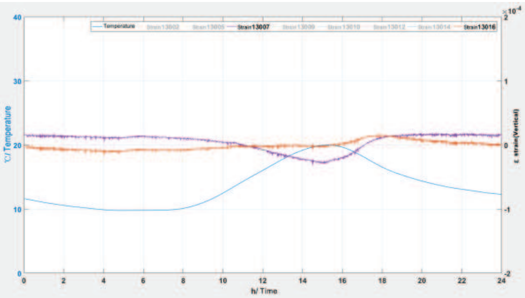
In order to select a more representative graphic, based on temperature and weather conditions, the data of January 1, 2018 is selected for display. The influence of temperature on the longitudinal strain of 1/2 arch rib is explored by the daily temperature difference. In order to more clearly characterize the correlation between temperature and strain measurement point, the upper and lower, left and right cross-section strain points and temperature of the arch rib are respectively drawn (Liu *et al.* 2019). Time history curve. As shown in Fig. 5, the X axis represents 24 hours of 1 day; the left Y_1 axis represents temperature, and the value ranges from [0, 40] °C; the right Y_2 axis represents the magnitude of temperature strain, and the value ranges from $[-2.2]\times10^{-4}$.



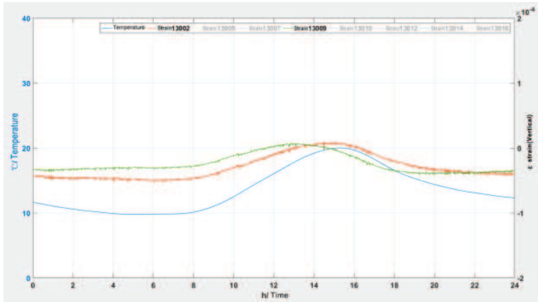
a)Arch rib upper section temperature and temperature strain time history curve



b）Arch rib lower section temperature and temperature strain time history curve



c)Arch rib left section temperature and temperature strain time history curve



d)Arch rib right section temperature and temperature strain time history curve

Figure. 5 Temperature and longitudinal strain time history curves for January 1, 2018

It can be seen from Fig. 5 that the longitudinal strain of the lower and right sections of the arch rib is positively correlated with the atmospheric temperature, and the slopes of the two are close to each other, and the degree of consistency is high; and the longitudinal section of the upper and left sections of the arch rib The strain has a negative correlation with the atmospheric temperature, and the slope of the strain change is significantly smaller than the slope of the change in atmospheric temperature (Wang *et al.* 2019).

In order to further verify the universality of the relationship between atmospheric temperature and arch rib strain, randomly selected 5 days of data collected and processed in April 2018,and the above five-day data can reflect the data characteristics of the April front by the K-S test of significance level = 0.1 (Zuk 2017). Calculate the correlation coefficient of the two, and the calculation formula is as shown in (1), and the calculation results are shown in Table 1.

$$R(X,Y) = \frac{\text{cov}(X,Y)}{\sqrt{Var[X]Var[Y]}} \tag{1}$$

Table 1. Arch rib air temperature and longitudinal strain data correlation coefficient table

Strain point number	13002	130010	13012	13016
Correlation Coefficient / Date	$\lvert R_1 \rvert$	$\lvert R_2 \rvert$	$\lvert R_3 \rvert$	$\lvert R_4 \rvert$
2018.04.05	0.9358	0.8025	0.9791	0.9281
2018.04.10	0.9433	0.8865	0.9771	0.8380
2018.04.16	0.9027	0.8728	0.9843	0.9151
2018.04.23	0.9193	0.9226	0.9792	0.8376
2018.04.30	0.9388	0.9587	0.9890	0.8723
average value	0.92798	0.88862	0.98174	0.87822

It can be seen from Table 1 that the average value of the correlation coefficient R between the arch rib strain measurement point and the atmospheric temperature is greater than 0.8, and the root is a linear correlation of height.

4.2 *Correlation analysis between strain measurement points and strain points of arch ribs*

The strain sampling frequency of the Tianyuan Bridge structural health monitoring system is 100 Hz, thus generating massive data. Through the study of the correlation between strain points, the amount of data can be effectively reduced and the calculation efficiency can be improved.
In order to study the correlation between different strain points of the rib, from January 2018 to May 2018, randomly selected for 8 days. Through the K-S test of significance level = 0.1, the above eight days of data can reflect the data characteristics of the time period. The calculation results are shown in Table 2.

Table 2. Arch rib temperature strain data correlation coefficient table

Strain point number	13012&13014	13002&13009	13005&13010	13007&13016
Correlation Coefficient / Date	$\|R_1\|$	$\|R_2\|$	$\|R_3\|$	$\|R_4\|$
2018.01.07	0.9966	0.7519	0.9297	0.0052
2018.01.31	0.9713	0.2561	0.8735	0.5905
2018.02.16	0.9927	0.6425	0.9767	0.0774
2018.03.19	0.9855	0.0586	0.9633	0.4378
2018.03.28	0.9988	0.6044	0.9779	0.6989
2018.04.05	0.9890	0.1681	0.9814	0.8134
2018.04.21	0.9962	0.1966	0.9830	0.8994
2018.05.16	0.9964	0.7016	0.9920	0.9838
average value	0.9908	—	0.9597	—

It can be found from Table 2 that the correlation coefficient R of the lower side strain measuring points 13012 and 13014 of the arch rib and the upper side measuring points of the arch ribs 13005 and 13010 are stable, all above 0.80, which is highly linearly correlated. Therefore, in the subsequent data processing work, one of the upper and lower cross sections of the arch rib can be selected for analysis. However, the correlation coefficient R of the left and right sections of the arch rib is unstable, and a reasonable average value cannot be obtained. Therefore, the data processing of the measurement points on the left and right sides of the arch rib should be analyzed separately to ensure the accuracy of the later data analysis results.

5 Conclusion

Based on the health monitoring data of Tianyuan Bridge, the paper draws the following conclusions from single arch rib strain measurement point and temperature correlation analysis, multiple arch rib strain measurement points and temperature correlation analysis:

- The temperature and strain signals contain two identical frequency components with corresponding periods of 24h and 12h, respectively. The amplitude of the periodic components at 24h and 12h is significantly larger than that of other periodic components. To a certain extent, it is indicated that a large part of the arch rib strain of the Tianyuan Bridge is caused by temperature strain.

- The correlation coefficient R between the temperature and the rib strain is in the range of $0.5 < |r| < 1$, which is a significant linear correlation. When performing arch rib strain and temperature action analysis, a linear fit can be considered to establish a correlation model.
- There is a significant linear correlation between the rib strain measurement points. When monitoring data mining, a representative wake-up analysis can be selected for the strain measurement points with significant correlation, which can reduce the large amount of data processing and analysis work. It also has certain guiding significance for the arrangement of strain measurement points for health monitor in.

References

Dong X, Deng Z, Li S, Gu S., Research on Sun Light Temperature Field and Thermal Difference Effect of Long Span Box Girder Bridge with Corrugated Steel Webs. *Engneering Mechanics*., (9)34, 230-238, Sep, 2017.

Li M, Ren W, Hu Y, Separating temperature effect from dynamic strain measurements of a bridge based on analytical mode decomposition method. *Vibration and Shock*, 31(21): 6-10, 2012.

Li M, Ren W, Huang T, Wang N, Extraction of Bridge Strain Temperature Effect Based on EMD and IMF Energy. *Journal of Highway and Transportation Research and Development*., (7)32, Jul. 2015.

Liu Y, Zhang H, Deng Y, Nan Jiang., Research on Temperature Field Characteristics of Steel Box Girder of Suspension Bridge Based on Measured Data. *China Journal of Highway and Transport*., (3)30, 56-64, Mar, 2017.

Liu Z, Chen Y, Zhou L., Analysis of characteristics and correlation for temperature and strain based on long-term bridgehealth monitoring big data. *Science Technology and Engineering*., 18(35), 72-79, Dec, 2018.

Liang L, Gao N, Li J, Image Denoising Method Based on Wavelet Transform and Mean Filtering. *Computer & Digital Engineering*, 5, 1229-1332, 2019.

Liu Y, Liu J, Zhang N, Review on solar thermal actions of bridge structures. *China Civil Engineering Journal*., (5)52, 59-78, May, 2019.

Maher D., The effects of differential temperature on continuous prestressed concrete bridges. *Institute Engineers, Civil Engineering Transactions*, (1)GE12, 29-32, 1970.

Sun Y, Zhao Z, Real-Time Seperation of Temperature Effect on Dynamic Strain Monitoring and Moving Load Identification of Bridgr Structure. *Engineering Mechanics*., (2)36, 186-194, Feb, 2019.

Wang D, Zhang Y, Liu Y, Vertical temperature gradient effect analysis of steel-concrete composite deck system on steel truss stiffening girder with health monitoring. *China Journal of Highway and Transport,* (11)28, 29-36, 2015.

Zuk W., Thermal and shrinkage stresses in composite beams. *ACI Structural Journal*, (9)58, 327-340, 1961.

Zeng Q, Han D, Ma T, Temperature Effect Analysis of Prestressed Concrete Box Girder Bridge. *Journal of Central South University (Natural Science Edition).*, (41)6, 2360-2366, 2010.

Zhang Y, Yang N, Li C, Research on Temperature Field of Steel Box Girder Without Pavement Caused by the Solar Radiations. *Engineering Mechanics*., (6)28, 156-162, Jun, 2011.