Effect of Ambient Temperature on Behavior of a Steel Arch Bridge Based on SHM Data

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ABSTRACT: Briefly introduce the project overview of Tianyuan Bridge and the composition of the Tianyuan Bridge structural health monitoring system. By using the wavelet denoising method, at the mid-span of arch rib strain data and the temperature data of the environment in the structural monitoring system of the Tianyuan Bridge are preprocessed. Using the processed data, preliminary analysis of temperature, strain and other monitoring data, to obtain the temperature and strain changes in a day; the correlation between the single strain point and temperature and the correlation between multiple strain points are further analyzed in the midspan section of arch rib .The results show that there is a significant linear relationship between some strain points and temperature; there is a significant linear relationship between some strain points. For the strain points with correlation, select representative points for analysis. The amount of data processing for establishing a correlation model later can be greatly reduced.

1 INTRODUCTION

The bridge structure is exposed to the external environment and is subject to periodic temperature changes, changes in solar temperature and thermal conductivity of the material, as well as the combined effects of the sun's surface[1]. Under the combined influence of the above various temperature effects, the unstable temperature field is easily generated inside the structure, which will cause the temperature gradient of the component section to appear in different directions. This temperature distribution causes uneven thermal stresses inside the component[2]. If the thermal stress generated is too large, it will affect its normal use. For steel bridge structures, uneven temperature fields can cause uneven deformation inside the components, and long-term temperature stress increases the creep effect of the material itself. Therefore, exploring the temperature has practical significance for the stress of the bridge structure[3].

2 OVERVIEW OF STRUCTURAL HEALTH MONITORING SYSTEM FOR TIANYUAN BRIDGE

Tianyuan Bridge is a half-through steel arch bridge with a span of 120m and width of 32m. The arch axis is parabolic. The single box arch rib is located in the middle of the deck girder. 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.The panoramic photo of the bridge is shown in Fig. 1.

Figure. 1 Panorama of Tianyuan Bridge

In this real-life bridge monitoring application, the instrumentation plan is designed to monitor the most critical structural components. The current installation consists of more than 100 sensors and summary of the sensors used in SHM system is shown in Table 1. Fig. 2 shows the positions of these sensors.

Table 1. Tianyuan Bridge real-time monitoring project and number of sensors

No.	Parameter		Sensor type	Amount
1	Environmental effect	Temperature	Thermometer	4
		Humidity	Hygrometer	4
2	Loading sources	Weigh-in-motion system		6
		Traffic condition	Video Camera	2
3		Tension in hanger	Strain sensors	20
4		Deflection at arch crown	GPS	2
5	Structural responses	Vibration in deck girder	Acceleration sensor	30
6		Strain in arch rib	Dynamic strain sensor	16
7		Strain in deck girder	Dynamic strain sensor	42
Total				126

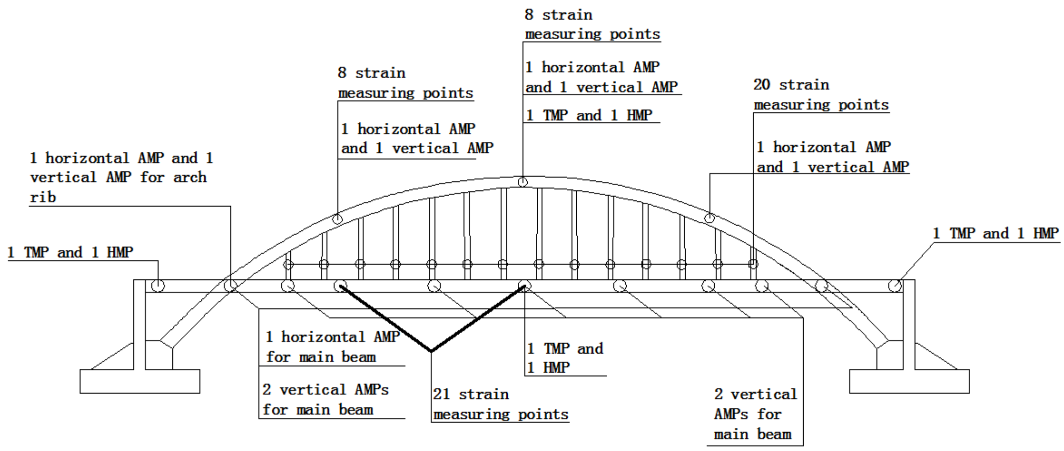


Figure. 2 Arrangement of sensors.
(TMP - temperature measuring point; HMP - humidity measuring point; AMP - acceleration measuring point)

3 ANALYSIS OF THE CORRELATION BETWEEN AIR TEMPERATURE AND LONGITUDINAL STRAIN MONITORING DATA

Through wavelet denoising method, remove strain caused by vehicle load and random noise[4].The ε temperature strain curve generated by the air temperature can be extracted from the original strain monitoring data[5]. Therefore, when performing correlation analysis of longitudinal strain and air temperature monitoring data, a two-axis can be established, and the air temperature and temperature-strain time-history curves are placed in the same two-axis to observe and analyze the existing rules[6].The strain sensor of arch rib midspan is arranged as shown in Fig. 3.

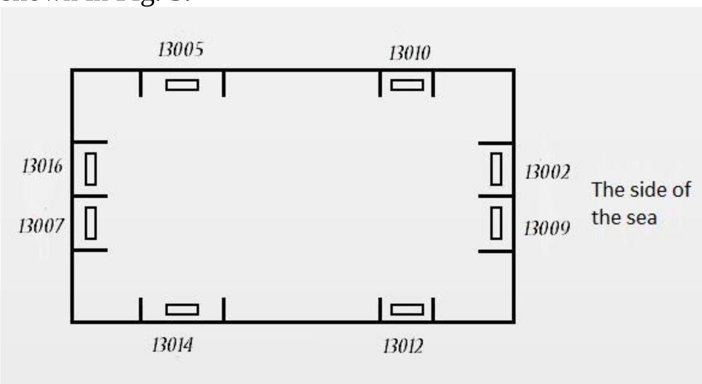
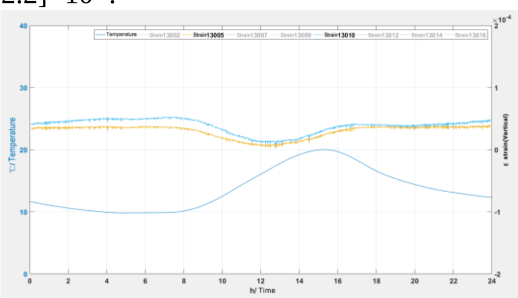


Figure. 3 Arrangement and numbering of strain measuring points in arch rib midspan

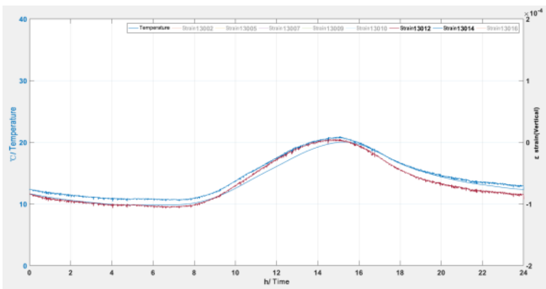
The longitudinal strains mentioned in the following article are all stripped of the effects of vehicle loads and random noise, only the longitudinal strain caused by temperature changes.

3.1 Arch rib longitudinal strains measurement points and air temperature correlation analysis

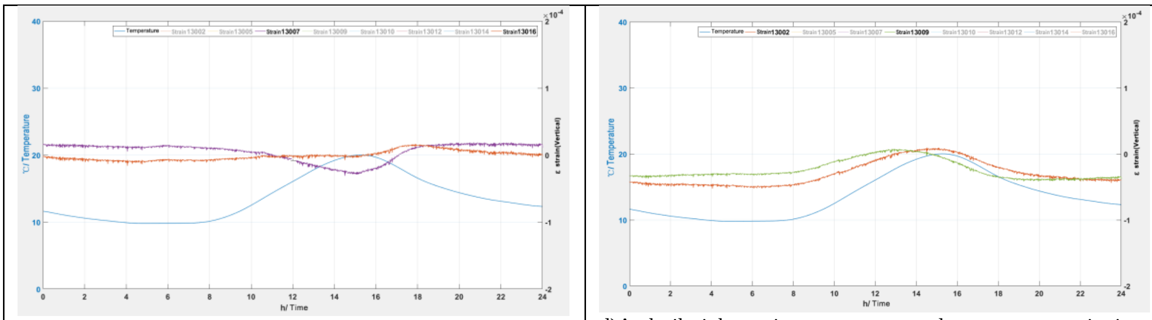
In order to select a more representative graphic, based on temperature and weather conditions, the data of January 1, 2018 is selected for display. In order to more clearly see the correlation between temperature and longitudinal strain (external load, longitudinal strain caused by random noise has been stripped, longitudinal strain caused by temperature only), the longitudinal direction of the upper, lower, left and right surfaces of the arch rib, respectively Strain and temperature are presented separately in a single figure. The temperature and longitudinal strain time history curves are shown in Fig. 4.Wherein, the X axis represents 24 hours of 1 day; the left Y_1 axis represents temperature, and the value ranges from [0, 40] ℃; the right Y_2 axis represents the magnitude of temperature strain, and the value ranges from [-2.2]×10^{-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. 4 Temperature and longitudinal strain time history curves for January 1, 2018

It can be seen from Fig. 4 that the temperature strain at the lower side and the right side of the arch rib is positively correlated with the ambient temperature, and the temperature strain at the upper side and the left side of the arch rib is negatively correlated with the environment;the rate of temperature strain change on the left and right sides of the arch rib is significantly smaller than the rate of change of the temperature strain on the upper and lower sides of the arch rib;there is a correlation between the two strain points of the same side section of the arch rib.

In order to further prove the correlation between longitudinal strain and air temperature, the monitoring data of April 2018 was randomly selected for 5 days, and the calculation and statistics of the first correlation number were performed; the correlation coefficient calculation formula is as shown in (1). The calculation results shown are shown in Table 2.

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

Table 2. Arch rib air temperature and longitudinal strain data correlation coefficient table

Strain point number	13002	13007	13009	130010	13012	13016
Correlation Coefficient / Date	$\lvert R_1 \rvert$	$\lvert R_2 \rvert$	$\lvert R_3 \rvert$	$\lvert R_4 \rvert$	$\lvert R_5 \rvert$	$\lvert R_6 \rvert$
2018.04.05	0.9358	0.5629	0.3519	0.8025	0.9791	0.9281
2018.04.10	0.9433	0.2840	0.3659	0.8865	0.9771	0.8380
2018.04.16	0.9027	0.7306	0.0723	0.8728	0.9843	0.9151
2018.04.23	0.9193	0.5454	0.3636	0.9226	0.9792	0.8376
2018.04.30	0.9388	0.5366	0.1833	0.9587	0.9890	0.8723
average value	0.92798	0.5319	0.2674	0.88862	0.98174	0.87822

According to the correlation coefficient R, different degrees of linear correlation judgment are determined:

$$\begin{cases} |R| \le 0.3: \text{Very weakly related or not linearly related} \\ 0.3 \le |R| \le 0.5: \text{Low linear correlation} \\ 0.5 \le |R| \le 0.8: \text{Significan t linear correlation} \\ |R| \ge 0.8 \text{Highly linearly correlated} \end{cases}$$

It can be found from Table 2 that the absolute value of the correlation coefficient R between the strain measuring points 13012, 13010, 13012 and 13016 and the air temperature is greater than 0.80, which is highly linearly related.The absolute values of the correlation coefficients R of the remaining two strain points 13007 and 13009 are 0.5319 and 0.2674, respectively, which are significant linear correlation and low linear correlation, respectively, mainly due to the existence of longitudinal temperature difference.

3.2 Correlation analysis between strain measurement points and strain points of arch ribs

Due to the structural health monitoring longitudinal strain sampling frequency of 100 Hz, the amount of data is too large. Therefore, by studying 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, 5 days of longitudinal strain data were randomly selected from January 1, 2018 to May 19, 2018, and the correlation coefficients of the two pairs were calculated using MATLAB programming; the correlation coefficient calculation formula is as shown in (1). The results are shown in Table 3.

Table 3. 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
2018.02.16	0.9927	0.6425	0.9767	0.0774
2018.03.19	0.9855	0.0586	0.9633	0.4378
2018.04.21	0.9962	0.1966	0.9830	0.8994
2018.05.16	0.9964	0.7016	0.9920	0.9838
average value	0.99348	—	0.96894	—

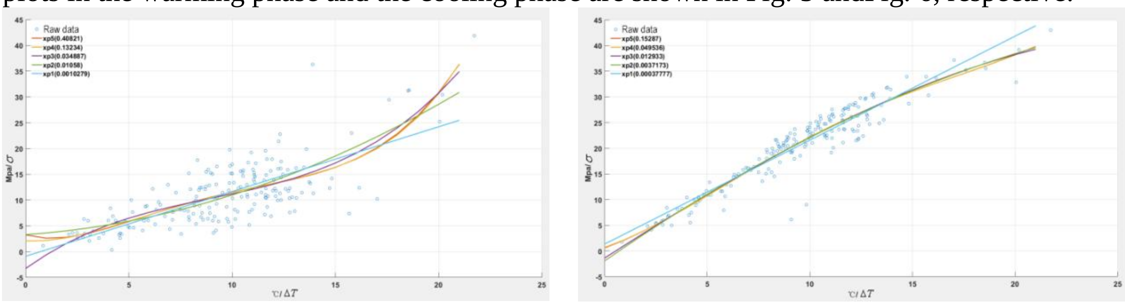
It can be found from Table 3 that the correlation coefficient R of the lower side strain measuring points 13012 and 13014 of the arch rib and the upper side measuring points of the arch ribs 13005 and 13010 are stable, all above 0.80, which is highly linearly correlated.Therefore, in the subsequent data 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[7].

4 CORRELATION ANALYSIS BETWEEN DAILY STRESS DIFFERENCE AND DAILY TEMPERATURE DIFFERENCE

In order to further study the temperature effect of the mid-support steel arch bridge, it can be measured by calculating the stress caused by the temperature difference. According to the daily temperature time history curve, it can be found that the daily ambient temperature change of the bridge structure can be roughly divided into two stages: the temperature rising stage from about 6 o'clock to about 16 o'clock and the cooling stage from about 16 o'clock to about 24 o'clock (Excluding some rainy weather, because the warming and cooling of the rainy days is not obvious). The temperature stress is calculated by collecting the strain values at 6 o'clock, 16 o'clock, and 24 o'clock every day. The difference in temperature stress can be calculated according to formula (2).

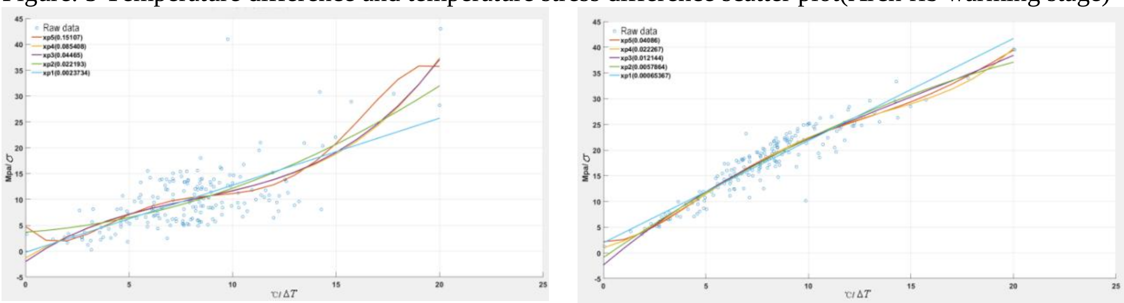
$$\sigma_T = E \bullet \varepsilon_T \tag{2}$$

The 13010 and 13014 measuring points were selected, and the temperature difference stress value of January 2018 was calculated by formula (2).The temperature stress difference scatter plots in the warming phase and the cooling phase are shown in Fig. 5 andFig. 6, respective.



a) measuring point(13010) b) measuring point(13014)

Figure. 5 Temperature difference and temperature stress difference scatter plot(Arch rib warming stage)



a) measuring point(13010) b) measuring point(13014)

Figure. 6 Temperature difference and temperature stress difference scatter plot(Arch rib cooling stage)

The Matlab data fitting toolbox is used to fit the curve from one to four powers,and the Var function is used to calculate the variance of the fitted curve to select the appropriate curve to obtain the relationship between the temperature difference and the temperature stress difference of different channel numbers in different working conditions. In order to determine the temperature stress difference under four different operating conditions based on the monitoring data.Arch rib overall temperature change scatter plot fitting curve variance statistics as shown in Table 4.

Table 4. Arch rib overall temperature variation scatter plot fitting curve variance statistics

Temperature change	Measuring point / power	13010	13014
Warming phase	Power function	1.028E-03	3.778E-04
	Second power function	1.058E-02	3.717E-03
	Third power function	3.489E-02	1.293E-02
	Fourth power function	1.323E-02	4.954E-02
Cooling phase	Power function	4.082E-01	1.529E-01
	Second power function	2.373E-03	6.537E-04
	Third power function	2.219E-02	5.786E-03
	Fourth power function	4.465E-02	1.214E-02

In Table 4, it can be seen that when the order of the fitting curve is 1, the variance value is the smallest, so the fitting curve with the order of 1 is selected as the difference between the temperature difference and the temperature stress difference of each channel under different temperature changes. Relationship. The specific relationship is shown in Table 5.

Table 5. The relationship of temperature difference and temperature stress difference

Temperature change / Measuring point	Warming phase	Cooling phase
13010	y=1.3x-0.89	y=1.3x-0.22
13014	y=2x-1.3	y=2x-2

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:

(1) 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.

(2) 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.

(3)By plotting the temperature difference and temperature stress difference scatter plot and fitting the curve from one to four powers, when the order is 1, the variance value of the fit curve is the smallest, and the relationship of temperature difference and temperature stress difference of different points are obtained.

6 REFERENCES

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