Research Journal of Applied Sciences, Engineering and Technology 6(23): 4375-4380, 2013
DOI:10.19026/rjaset.6.3439
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: January 24, 2013 Accepted: February 25, 2013 Published: December 15, 2013

Research Article

Comparative Study on Pavement Temperature Features of Bridge Deck and Road Pavement

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Abstract: The objective of this study was to comparatively analyze the difference of pavement temperature of bride deck and road pavement. The asphalt pavement temperature of road pavement and bride deck were tested in Guozigou area of Xinjiang, China. And the air temperature, wind speed, humidness and sunlight radiation were collected. Further, the distribution features of asphalt pavement of bridge deck and road pavement were comparatively analyzed. At last, the predictive model of pavement temperature field for bridge deck and road pavement was set up. The results show that the pavement temperature and air temperature change synchronously. The pavement temperature of bridge deck is usually 66~13ºC higher than the air temperature and keeps close to it in winter. Compared with road pavement temperature, the temperature of bridge deck is characterized by being higher lowest-temperatures in winter, greater in temperature changes and lasting for longer time when it keeps its high temperature in summer. The predictive model of pavement temperature field for bridge deck and road pavement is proposed utilized linear function with five factors, namely air temperature, wind speed, humidness, sunlight radiation and pavement depth. The developed model was proved to be more accurate and closer to the measured temperature compared with LTPP and SHRP model.

Keywords: Bridge deck, distribution feature, pavement temperature field, predictive model

INTRODUCTION

With the rapid development of expressways in China, the bridge construction has also entered into peak period. However, the earlier damages of bridge deck, especially those of huge bridge deck, have been a hard-nut problem. The force acting on the bridge, vibration from traffic load and deflection were often the main causes for the damages. In addition, the features of the temperature for bridge deck may also worsen the service conditions and speed up the damages. At present, quite a few scholars have already conducted researches on the temperature field of road pavement, but they have not done much for that of bridge deck, especially for pavement of cement concrete bridges. In 2001, the British scholar Au monitored the temperature field of the Tsing Ma Bridge in Hong Kong and deduced that the sunlight radiation and temperature were the main factors affecting the pavement temperature field (Au, 2001). The British scholar Jones carried out simulation computation for temperature field only of steel bridge deck (Jones, 2001). Wang Qian from Chang'an University conducted tests for temperature field of 12 cement concrete bridges with asphalt concrete pavement and deduced the relationship between the paving temperature and atmosphere temperature and total sunlight radiation (Wang *et al*., 2009a, b). Liu Qiwei from South-East University did tests on temperature field on asphalt pavement of steel-concrete box bridges and suggested that the plane model between the boundary conditions and different initial temperature fields before the asphalt was paved should be used to calculate the pavement structure temperature field (Liu *et al*., 2006; Chen *et al*., 2009; Chen and Liu, 2009). Lan Zhongqiu set up a data model for analysis for SMA asphalt pavement temperature field of steel box bridges and conducted calculations for the relationship between the bridge surface temperature and local temperature of the highest temperature and lowest temperature of the year of 2000 on Haicang Bridge in Xiamen (Lan *et al*., 2003). Lu *et al*. (2007) analyzed the distribution features of temperature field on steel bridge deck and believed that the temperature field of steel bridge deck was characterized by being higher in temperature, having synchronous periodic changes between pavement surface temperature and atmosphere temperature (Lu *et al*., 2009, 2007). Clearly, all the above researches were focused on steel

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bridge deck. And also those results from road pavement temperature field cannot be used for cement concrete bridge deck. So, it was of significance to study the temperature field of cement concrete bridge deck.

In this study, the temperature sensor was buried under the cement concrete bridge deck pavement and road pavement of the same adjacent cross-section to test the temperature fields of the pavement during the highest temperature in summer and lowest temperature in winter. On the basis of this, the statistical analysis for distribution features of temperature field of both bridge deck and road pavement was conducted to reveal their special features. Finally, prediction models for temperature field of bridge deck and road pavement were sets up.

Temperature testing on spot: The research tests the asphalt pavement temperature field of both bridge deck and road pavement during the highest temperature in summer and lowest temperature in winter. The observation spot in summer time was on Jiaesu bridge on K4801 of national trunk highway 312 and that in winter time was near Sitai No. 1 bridge on K4666 of Lianyungang-Huoeguosi expressway, both of which were in Guozigou were in Xinjiang of China. The tests for the temperature field in summer highest period was conducted from August to September 2008 with 11 observation spots, including 5 spots for bridge deck and 6 spots for road pavement. Altogether 44 temperature sensors were buried with the depths of 0, 3, 7 and 10 cm, respectively. In January 2008, the tests for temperature field of winter low period were carried out with 11 observation spots. On the 6 spots for road pavement, 24 sensors were buried with the depths of 0, 3 7 and 10 cm, respectively. On the 5 spots of bridge deck, 20 sensors were buried with depths of 0, 3 and 7 cm, respectively.

COMPARATIVE ANALYSIS FOR PAVEMENT TEMPERATURE FEATURES

From the analysis for temperature test results, the following features of temperature fields of bridge deck and road pavement could be obtained:

- There were exist synchronous periodic changes between bridge deck and atmosphere temperature with the former happening a little later. The test results on January 25 were shown in Fig. 1, the surface temperature on bridge deck was the lowest between 5:00 to 6:00 am and then it gradually rises with its highest value at about 15:00 pm.
- The highest temperature in summer on bridge deck was often 6~13ºC higher than that of the atmosphere temperature and the highest temperature on road pavement was almost the same as that on the bridge deck, presented as Fig. 2.
- The lowest temperature in winter on bridge deck was almost the same as that of the atmosphere temperature, which was about 4ºC higher than that of road pavement, presented as Fig. 3.
- The comparison for the temperature changes in a day from 20 August to 5 September between road pavement and bridge deck was shown in Table 1. It was known that there was a greater fluctuation of temperature on bridge deck. The greatest daily temperature differences on bridge deck can reach as high as 31.7ºC and the average temperature difference was about 24.2ºC. The greatest daily temperature difference on road pavement was only 26.6ºC and the average temperature difference was about 22ºC.

Table 1: Comparison of temperature difference in one day

Pavement type	Max./ºC	Min./ºC	Ave/ºC
Bridge deck	31.7	12.0	24.2
Road pavement	26.6	11.3	22.0

Max.: Maximum; Min.: Minimum

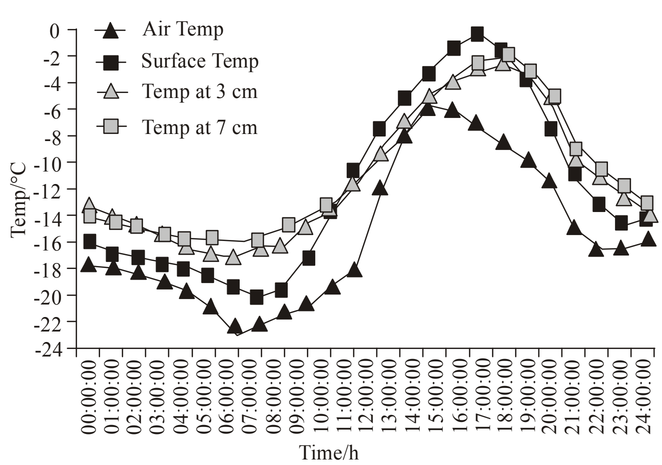

Fig. 1: Temperature test results on January 25

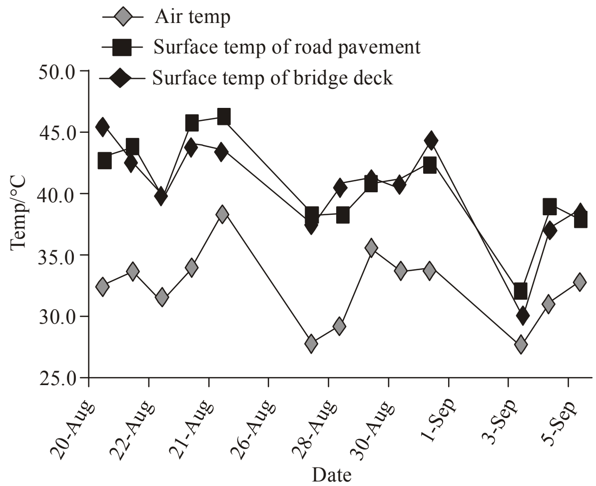

Fig. 2: Comparison of highest temperature

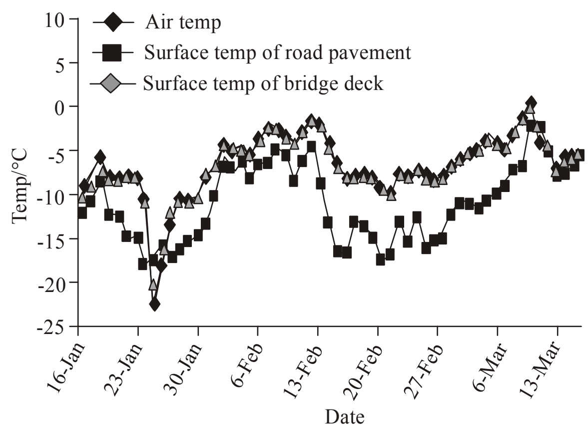

Fig. 3: Comparison of lowest temperature

Table 2: High-temperature duration time of different pavements

Pavement type	Temp/ºC	Duration time /h													Ave/h
		20-Aug	21-Aug	22-Aug	23-Aug	24-Aug	27-Aug	28-Aug	29-Aug	30-Aug	31-Aug	3-Sep	4-Sep	5-Sep	
Bridge deck	>45	2	0	0	2	2	0	0	0	0	0	0	0	0	0.5
	40~45	4	4	0	6	4	0	4	2	4	2	0	0	0	2.3
	35~40	2	4	6	4	4	4	2	4	4	2	2	6	4	3.7
Road pavement	>45	0	0	0	2	2	0	0	0	0	0	0	0	0	0.3
	40~45	4	4	0	4	6	0	0	2	4	2	0	0	0	2.0
	35~40	2	4	6	4	2	4	6	4	2	0	0	6	4	3.4

- As for the duration time of different pavements in a day during the high-temperature season, it was longer on bridge deck than that on the road pavement and the temperature requirements were harsher, shown in Table 2.

PREDICTIVE MODELS FOR TEMPERATURE FIELD

Environment affecting factors: The environment factors resulting in pavement temperature field changes were: atmosphere temperature, sunlight radiation, wind speed and humidness. Figure 4 shows the changing process of all the factors on the temperature field.

There was the similar changing law between pavement temperature and atmosphere temperature, the atmosphere temperature was used here to reflect the changing law of pavement temperature field. Table 3 shows the relative coefficients of their *m* times after the analysis for pavement temperature data and the atmosphere temperature data in Guozigou area. The results indicate that the road pavement temperature and

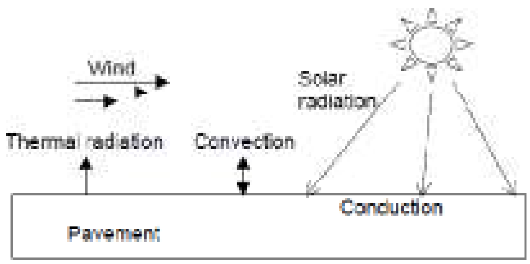

Fig. 4: The relationship between environment and pavement temperature

Table 3: Relative coefficients of m times

	Air temp T_a		
Pavement temp T_P	T_a	T_a^2	T_a^3
Road pavement	0.929	0.747	0.781
Bridge deck	0.987	0.826	0.873

atmosphere temperature were in their linear relation. The main reason for the differences was that the sunlight radiation in different areas was not the same, especially when there were changes of the latitude and altitude in these areas. In this study, the author has already eliminated the regional differences of the sunlight radiation factors and determined its calculation methods with reference of the related documents (Ali *et al*., 2010; Yang *et al*., 2006; Raul *et al*., 2008).

Step 1: Calculating sunlight radiation angle Γ by Eq. (1):

$$\Gamma = \frac{2\pi(d_{n-1})}{365} \tag{1}$$

where,
d_n: Date number in one year, from 1 to 365.

Step 2: Calculating eccentric coefficient E_0 by Eq. (2):

$$E_0 = 1.00011 + 0.034221\cos\Gamma + 0.00128\sin\Gamma + 0.000719\cos 2\Gamma + 0.000077\sin 2\Gamma \tag{2}$$

Step 3: Calculating sun altitude δ by Eq. (3):

$$\delta = (0.006918 - 0.399912\cos\Gamma + 0.070257\sin\Gamma - 0.006758\cos 2\Gamma + 0.000907\sin 2\Gamma - 0.002697\cos 3\Gamma + 0.00148\sin 3\Gamma)\times(\frac{180}{\pi}) \tag{3}$$

Step 4: Calculating sun-rise angle ω by Eq. (4). The time angle was the angle between the two positions when the sun reaches its highest position and when it rises and sets. When the sun rises, its time angle has negative value while it sets it has its positive value. When it was 12 o'clock, the time angle was 0°. With one more hour increasing or decreasing, it increases 15°:

$$\omega = \cos^{-1}(-\tan\phi\tan\delta) \tag{4}$$

where, φ: latitude.

Step 5: Calculating daily sunlight radiation by Eq. (5):

$$R_0 = \frac{24}{\pi} I_{SC} E_0 \sin\phi \sin\delta(\frac{\pi\omega}{180} - \tan\omega) \tag{5}$$

where,
R_0 : Daily sunlight radiation, MJ/ (m^2/d)
Is_c : Constant of daily sunlight radiation, equals 4.871 MJ/ (m^2/d)

Step 6: Calculating the total volume of sunlight radiation at a time period in a day at a place (from ω_1 to ω_2) by Eq. (6):

$$I_h = \frac{12\times 3600}{\pi} I_{sc}\left(1 + 0.033\cos\frac{360 d_n}{365}\right) \times \left[\cos\phi\cos\delta(\sin\omega_2 - \sin\omega_1) + \frac{\pi(\omega_2 - \omega_1)}{180}\sin\phi\sin\delta\right] \tag{6}$$

As all the environmental factors may affect temperature field on road pavement, humidness also affects it. Wind speed was the important factor that affects the heat circulation between the atmosphere and pavement structure. The greater the win speed, the more heat circulation may take place. Therefore, the author introduces wind speed factor and humidness factor into was predictive model in the hope of increasing the prediction accuracy.

Predictive model for daily highest temperature in summer: As for the highest temperature prediction in summer for road and bridge deck, the research uses daily highest temperature for atmosphere temperature

Table 4: Regressive coefficient of predictive model for daily highest temperature

Pavement type	a_1	a_2	a_3	a_4	a_5	a_6
Road pavement	-6.57	0.65	0.64	0.04	-0.05	-0.37
Bridge deck	-1.78	1.15	0.04	0.03	-0.03	-0.19

Table 5: Regressive coefficient of predictive model for daily lowest temperature

Pavement type	b_1	b_2	b_3	b_4	b_5	b_6
Road pavement	-8.57	1.09	0.25	0.006	0.051	0.398
Bridge deck	-3.97	1.00	0.22	-0.003	-9E-5	0.177

Table 6: Comparison for daily highest temperature/ºC

		Distance from surface of road pavement/cm				Distance from surface of bridge deck/cm	
Air temp/ºC	Calculating model	0	3	7	10	0	2
36	SHRP	58.4	53.4	48.6	45.9	58.4	54.9
	LTPP	56.3	51.1	47.5	45.7	56.3	52.4
	Author's	38.7	37.7	36.2	35.1	41.8	41.4
	Collected on the spot	39.0	37.5	36.8	35.1	41.3	40.7

Table 7: Comparison for daily lowest temperature/ºC

		Distance from surface of road pavement/cm				Distance from surface of bridge deck/cm		
Air temp/ºC	Calculating model	0	3	7	10	0	3	7
-12	SHRP	-9.0	-10.5	-8.7	-7.5	-9.0	-10.5	-8.7
	LTPP	-9.3	-7.2	-5.7	-5.0	-9.3	-7.2	-5.7
	Author's	-15.2	-16.3	-14.7	-13.5	-13.3	-12.8	-12.1
	Collected on the spot	-14.7	-15.7	-13.9	-12.2	-12.7	-12.4	-11.4

T_a and daily sunlight radiation volume R_0 for radiation volume. In consideration for the influence of humidness, wind speed and pavement depth, the predictive model for daily highest temperature was expressed as Eq. (7):

$$T_{P\max} = a_1 + a_2 T_{a\min} + a_3 R_0 + a_4 H_{ave} + a_5 W_{ave} + a_6 D \quad (7)$$

where,

T_{pmax} : Aily highest temperature of a certain depth of road and bridge deck, ºC
T_{amax} : Daily highest temperature, ºC
R_0 : Daily sunlight radiation volume, MJ/ (m^2/d)
H_{ave} : Daily average humidness, %
W_{ave} : Daily average wind speed, km/h
D : Pavement depth, cm
a_1~a_6 : Regressive coefficient

After pavement temperature, air temperature, sunlight radiation, humidness and wind speed were regressed, the predictive model for daily highest temperature on road pavement and bridge deck in Guozigou area in Xinjiang can be obtained, presented in Table 4. With the model, the daily highest temperatures on road pavement and bridge deck can be calculated and then they were compared with the collected data on the spot. The relative coefficients (R^2) were 0.947 and 0.978 show that the predictive model has very high accuracy.

Predictive model for daily lowest temperature in winter: The predictive model for both daily highest temperature and daily lowest temperature were almost the same. T_{amin} was used for daily lowest temperature and T_a for atmosphere temperature. The model can be expressed as Eq. (8):

$$T_{P\min} = b_1 + b_2 T_{a\min} + b_3 R_0 + b_4 H_{ave} + b_5 W_{ave} + b_6 D \quad (8)$$

where,

T_{Pmin} : Daily lowest temperature at a certain depth of asphalt pavement, ºC
T_{amin} : Daily lowest temperature, ºC
b_1~b_6: Regressive coefficient

The predictive model for the daily lowest temperature on bridge deck in Guozigou area in Xinjiang can be obtained, presented in Table 5.

Comparison for predictive models: In order to verify the applicability of the predictive models for temperature field on road pavement and bridge deck, the study compares the author's model with SHARP and LTPP models.

Different formulae were adopted to calculate the daily highest temperature and the daily lowest temperature, shown in Table 6 and 7. The results show that the values from the author's model were very much closer to the data collected on the spot.

CONCLUSION

Through the practical testing and analysis for the temperature fields on road pavement and bridge deck, the following conclusions have been obtained:

- The pavement temperature and air temperature change synchronously. The pavement temperature of bridge deck is usually 66~13ºC higher than the air temperature and keeps close to it in winter.
- Compared with the temperature of road pavement, the temperature of bridge deck was characterized by being higher during the lowest temperature in winter, greater in temperature fluctuation and longer in high-temperature duration. The requirements for high temperature of bridge deck were harsher than those of road pavement.

- Compared with SHARP model and LTPP model, the predictive model established for daily highest temperature in summer and lowest temperature in winter was more accurate and closer to the data collected on the spot.

ACKNOWLEDGMENT

This study was financially supported by the Special Fund for Basic Scientific Research of Central Colleges of China, Chang'an University (CHD2011JC164). National Western Traffic Building Technology Project (2008 318 000 29).

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