**Technical Paper**

ISSN 1997-1400 Int. J. Pavement Res. Technol. 8(4):259-266


# Local Calibration of EICM Using Measured Temperature Gradients and Numerical Analysis

Yoonseok Chung[1] and Alex Hak-Chul Shin[2+]

**Abstract:** Due to the daily and seasonal fluctuation of temperature gradients, accurate temperature gradients under local climatic conditions are imperative to correctly predict the performance of PCC pavements. In this study, temperature sensors were installed at various depths (0-, 6.4-, 12.8-, 19.2-, and 25.6-cm) in a PCC pavement section to monitor temperature gradients. Based on the measured daily and seasonal temperature data, correlations between air temperature and surface temperature, as well as surface temperature and slab temperature difference, were developed. A finite element analysis was performed to simulate the temperature variation in a PCC pavement, and the analysis results were compared to the field measurement. A local calibration of the enhanced integrated climatic model (EICM) was conducted by comparing the field-measurements with the EICM-predicted temperature gradients. The conclusion demonstrated that surface temperature, rather than air temperature, would better predict temperature gradient in PCC pavements for the input data in EICM.

**DOI**: 10.6135/ijprt.org.tw/2015.8(4).259

***Key words**: EICM; Local calibration; PCC pavement; Temperature gradient.*

## Introduction

One of the most important environmental factors for designing and predicting the performance of Portland cement concrete (PCC) pavements is temperature. Temperature gradients throughout the slab thickness play a key role in calculating stresses in PCC pavements, known as curling. Curling induces tensile stresses at the bottom of concrete pavement during the day, while tensile stresses are caused at the top of concrete pavement during the night [1]. Due to the variable characteristics of curling stresses, a result of daily and seasonal fluctuations in temperature gradients, an accurate measurement is necessary to correctly predict the performance of PCC pavement of temperature gradients in different local climatic conditions.

Many researchers agree that the temperature gradient through the slab thickness is nonlinear [2-4]. Choubane and Tia divided the temperature profiles into three components: a component that causes axial displacement; a component that causes the bending; and a nonlinear component [4]. In order to simulate the nonlinear temperature gradient through slab thickness, a quadratic equation was suggested as a function of depth. Guo and Rice proposed a third-order polynomial equation as not only sufficient, but also necessary in the numerical simulation of nonlinear temperature profiles [5]. Therefore, a third-order polynomial equation is considered as an appropriate equation to simulate nonlinear temperature gradients throughout the slab thickness.

The enhanced integrated climatic model (EICM) represents a one-dimensional coupled heat and moisture flow model, adopted for use in the mechanistic-empirical pavement design guide (MEPDG) [6]. In 1989, an integrated climatic model (ICM) was introduced, which combined three models: the climatic-material-structural model (CMS); the cold regions research and engineering laboratory (CRREL); and the infiltration and drainage model (ID). The EICM was released after further improvement of ICM through the NCHRP 1-37A project [7]. The EICM requires climatic data, obtained from the weather station, as input data: temperature, wind speed, sunshine, precipitation, humidity, and water table [8]. The climatic data can be found at the MEPDG website for an average of ten years, or can be generated manually, using local climatic data [9]. The typical outputs of EICM are a) hourly PCC temperature profiles for use in cracking and faulting models for jointed plain concrete pavement (JPCP); b) punch-out for continuously reinforced concrete pavement (CRCP); c) a freezing index for JPCP performance prediction; d) monthly humidity values for use in JPCP and CRCP modeling of moisture profiles.

By incorporating EICM, MEPDG pays more attention to the climatic effect on design procedures than the 1993 American Association of State Highway and Transportation Officials (AASHTO) design guide [6]. In the 1993 AASHTO design guide, only 4% of the guide addresses drainage and climatic effects; the majority of the information focuses on the weighted average of the subgrade support [8]. On the other hand, MEPDG uses 38% of its design guide in order to explain the effect of climatic condition on the design procedures, such as the climatic effect on material properties, as well as temperature influence on slab curling and warping. Some input parameters of EICM directly affect the performance of PCC pavements. Temperature and solar radiation impact joint load transfer, freeze and thaw cycle, slab curling, and crack width. Wind speed is a critical factor for heat transfer at the pavement surface. Humidity directly influences moisture warping, dry shrinkage, and initial crack width.

The EICM was designed and calibrated using nationwide climatic data, so that local calibration processes based on regional climatic

[1] Construction R&D Department, Korea Agency for Infrastructure Technology Advancement (KAIA), 286 Simin-daero, Dongan-gu, Anyang-si, Gyeonggi-do, 431-060, South Korea.

[2] Department of Civil and Environmental Engineering, Southern University and A&M College, 311 Pinchback Engineering Building, Baton Rouge, LA 70813, USA.

[+] Corresponding Author: E-mail hakchul_shin@subr.edu

Note: Submitted October 23, 2014; Revised March 16, 2015; Accepted April 5, 2015.

patterns and material properties are essential to enhance the reliability of the outputs. Ahmed et al. evaluated the suitability of the EICM model to predict subsurface temperature conditions in New Jersey [10]. The validation procedures were conducted by comparing the EICM prediction values with the field measurement values for each test section. Since specific climatic data from the weather station, such as wind speed and percentage sunshine, were not available for the test section, regional average values were used. According to a sensitivity analysis of two unavailable parameters, the impact of wind speed on the predicted pavement temperature becomes more significant than that of the sunshine percentage. The report stated that EICM-predicted surface temperatures tend to be 5 to 10 ℃ greater than the field-measured temperature; the study also noted that discrepancy was improved below the 30.5-cm depth from the surface. The study concluded that there exists no strong correlation between EICM-predicted and field-measured temperatures. Furthermore, an adjustment of the EICM is required in order to effectively implement the EICM in New Jersey.

A temperature calibration of the EICM was performed by utilizing long-term pavement performance (LTPP) data in New Mexico [11]. Since the percentage of sunshine was not available from LTPP data for the test sites, assumptions were made based on the local historical data in order to obtain the percentage of sunshine for each site. The study indicated that the measured surface temperature was always higher than the EICM-predicted surface temperature, due to a special soil condition in New Mexico. A correlation between the measured surface temperature and the EICM-predicted surface temperature was presented as shown in Eq. (1).

$$\begin{aligned} &Surface\ temperature\ ({}^\circ F) \\ &= 0.9193 \times (EICM - predicted\ temperature\ ({}^\circ F)) + 14.085 \end{aligned} \tag{1}$$

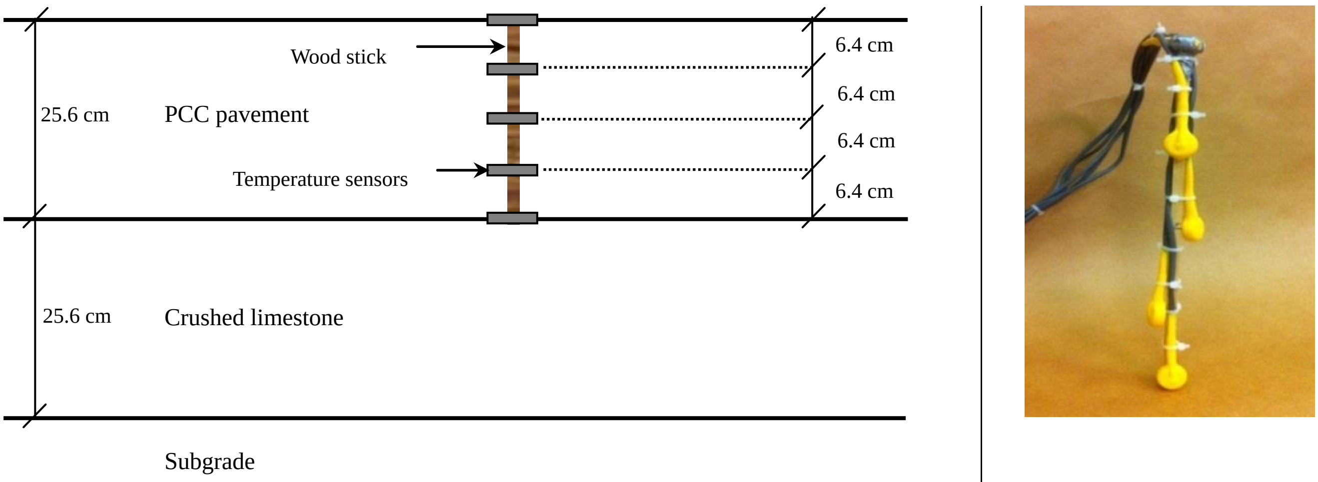
The objectives of this study were to characterize the variations of daily and seasonal temperature gradients throughout the slab thickness under local climatic conditions, to develop a correlation between air temperature and slab temperature difference, and to perform local calibration of EICM by utilizing measured temperature gradients and numerical analysis.

## Field-measured Temperature in a PCC Pavement

### Sensor Installation and Data Collection

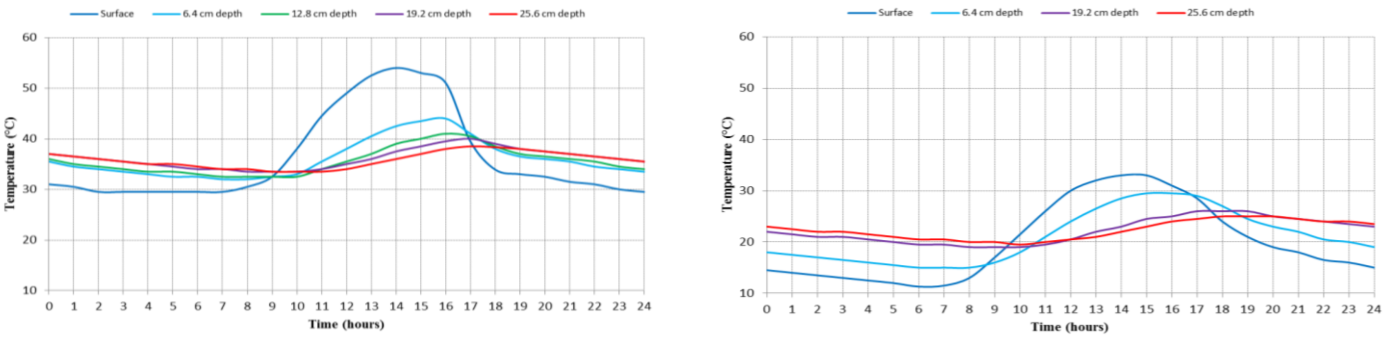
In order to monitor the daily and seasonal variations of temperature profiles, temperature sensors were installed at various depths of the existing PCC pavement. The pavement section is located on Northline Road, West Baton Rouge, Louisiana. The concrete mix design was conducted according to LA DOTD specification, and coarse aggregates with 6.4-cm maximum size, water reducer, and air entrainment agents were used [12]. However, the detail mix design is not known. The subgrade soil is categorized as CH (fat clay) with respect to United Soil Classification System (USCS), as well as A-7-6 (clayey soil) with respect to the AASHTO [13]. A base course layer (25.6-cm thick crushed limestone) was placed on the compacted roadbed, and a 25.6-cm thick Portland cement concrete surface layer was placed on top of the base course, using a slip form paving method. The temperature sensor (iBotton), manufactured by the Transtec Group, has a 1.9-cm diameter and 0.6-cm thickness. The size of the sensor is small enough for installation within the limited thickness of PCC pavements. The sensors are covered by rubber materials in order to protect from moisture. The temperature sensors were installed at various depths (0-, 6.4-, 12.8-, 19.2-, and 25.6-cm) from the pavement surface, as shown in Fig. 1. The sensors were set to measure temperature at twenty-minute intervals. The slab temperatures at various depths were measured from May 24 to November 29, 2011. Interruption of a continuous data collection was experienced due to sensor replacement coupled with technical difficulties. A limited storage capacity required a collecting of temperature every 28 days in order to obtain continuous data. The pocket PC provided by the manufacturer collected data by means of connecting the cable to the temperature sensor wire. The measurement range of the temperature sensor is -10 to 85℃, and the precision is ±1℃ of reading value.

### Typical Temperature Gradients



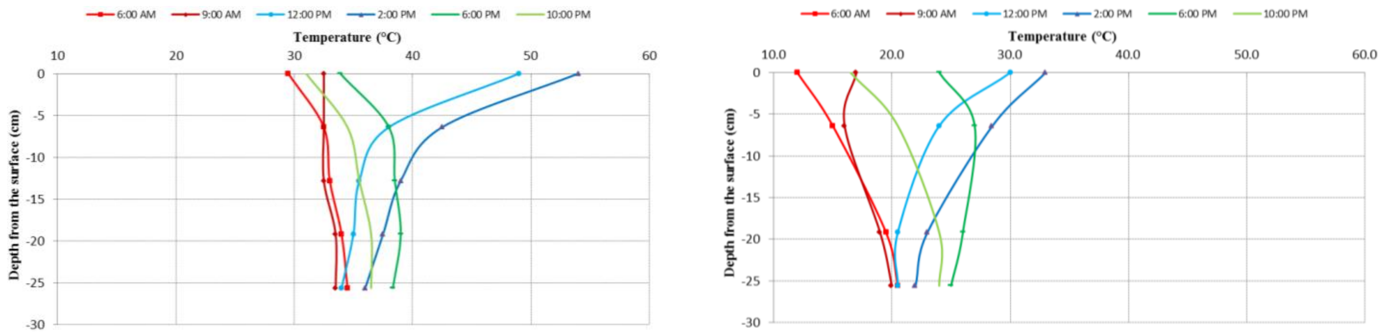

(a) Sensor locations in PCC pavements (b) Sensors installation

**Fig. 1.** Sensor Locations in PCC Pavement.




(a) Daily temperature profiles in June (b) Daily temperature profiles in November

**Fig. 2.** Typical Daily Temperature Profiles at Various Depths in PCC Pavement.




(a) Daily temperature gradients in June (b) Daily temperature gradients in November

**Fig. 3.** Daily Temperature Gradients of 10-in. Thick PCC Pavement.

Fig. 2 shows a typical daily temperature variation at each sensor in the PCC pavement in June and November, respectively. In the figure, several points that characterize the daily temperature variations should be noted. Due to a direct effect of sunshine and air temperature, the surface temperature has the highest values during the day, with the lowest values at night. The surface temperature reaches its peak value at around 2 p.m., and the lowest value occurs at around 6 a.m. The peak values of each depth gradually delay in a descent from the surface: the peak values at 6.4-cm and 12.8-cm depth occur at 4 p.m.; and, the peak values at 19.2-cm and 25.6-cm depth occur at 5 p.m. All the measured temperatures at every depth in the PCC pavement become close together at both 9 a.m. and 5 p.m. in June. The maximum surface temperature reaches 54.0℃ and 33.0℃ in June and November, respectively.

Fig. 3 shows the variations of temperature gradients in the PCC pavement in June and November. The temperature variation at the slab surface is 24.5℃ and 21.7℃, while the temperature variation at the bottom of the slab is 4.3 and 5.0℃ in June and November, respectively. In June, the temperature gradient changes remarkably up to 7-cm depth from the surface at 12 p.m. and 2 p.m., and the temperature gradient appears very stable throughout the slab thickness at 9 a.m., as shown in Fig. 2(a).

### Correlation between Air and Surface Temperature

The measured temperature at the pavement surface was found to be much higher than the air temperature collected from the weather station. One reason is that air temperature is normally measured at 1.2-m above the ground; the thermometer is protected from direct sunshine and precipitation by the instrument shelter [14]. On the other hand, the surface temperature sensor was exposed to direct sunshine and precipitation to measure a realistic surface temperature on the pavement. Thus, any temperature discrepancy between air and pavement surface temperature is caused by differing procedures of measurements. The typical temperature difference between air and pavement surface temperatures in both June and November is presented in Fig. 4. The pavement surface temperature was measured in PCC pavement as described in the previous section. The air temperature was obtained from the weather station at Baton Rouge Airport. The temperature difference increases remarkably during the daytime, and its peak value of 18.4℃ appears at 2 p.m. in June, while 14.8℃ appears at 1 p.m. in November, respectively. The surface temperature remains higher than the air temperature during nighttime and the minimum difference appears at 8 a.m. (3.3℃) in June.

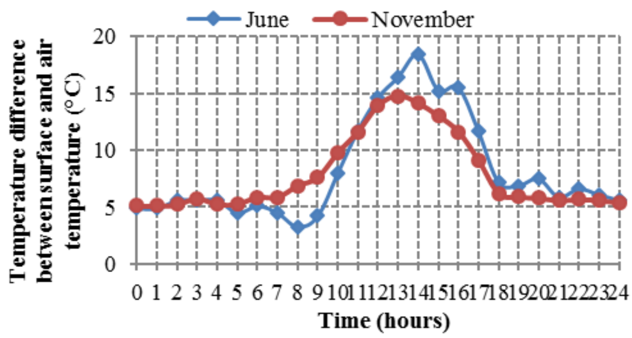
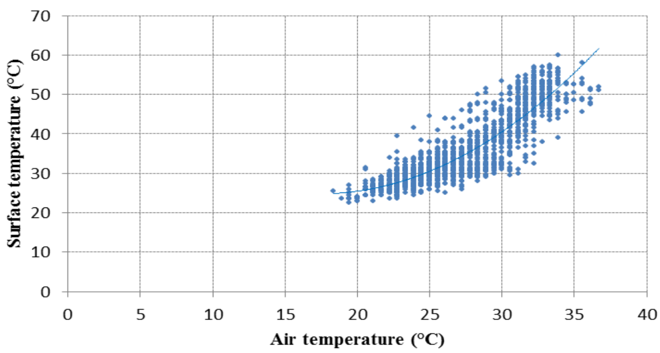
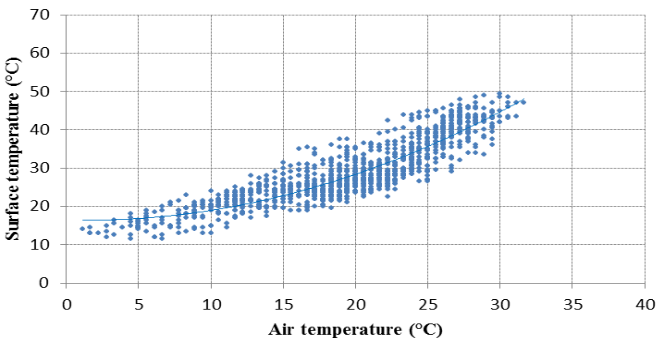



**Fig. 4.** Typical Temperature Differences between Surface and Air Temperature.

Fig. 5 shows the correlation between pavement surface temperature and air temperature for two periods (May to August and




(a) From May to August




(b) From September to November

**Fig. 5.** Correlation between Surface and Air Temperatures.

September to November). The correlation between two temperatures is not a linear, but a second-order polynomial. Eqs. (2) and (3) can be used to predict pavement surface temperature, using the air temperature available from the weather station. The temperature unit of the following formulas is in °C. $R^2$ values of each equation are 0.795 and 0.804, respectively.

From May to August,

$$Surface\,temp. = 0.099\times(Air\,temp.)^2 - 3.450\times(Air\,temp.) + 54.793 \quad (2)$$

From September to November,

$$Surface\,temp. = 0.035\times(Air\,temp.)^2 - 0.093\times(Air\,temp.) + 16.433 \quad (3)$$

## Correlation between Air Temperature and Slab Temperature Difference

The slab temperature difference is important in calculating the curling stress in PCC pavements. The slab temperature difference is defined as the temperature difference between the top and bottom surface of the slab. The higher slab temperature difference induces more curling, and consequently presents a high possibility of cracking in concrete pavements. The typical trend of slab temperature difference in June and November is presented in Fig. 6. The maximum slab temperature difference of 18.0°C in June and 11.2°C in November occurs at 2 p.m.; the maximum value should be used to find the most vulnerable case to crack. The slab temperature difference shows negative values at night, which means that the surface temperature is lower than the bottom temperature.

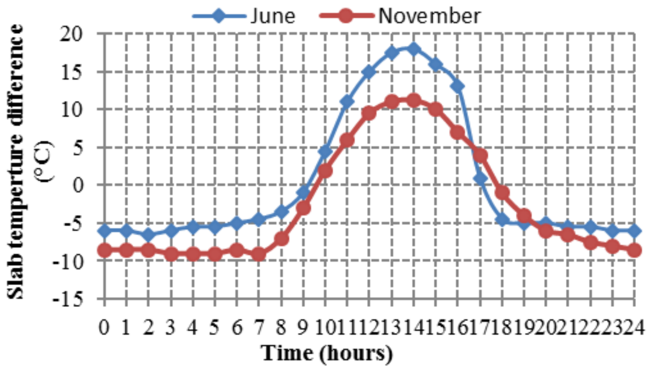
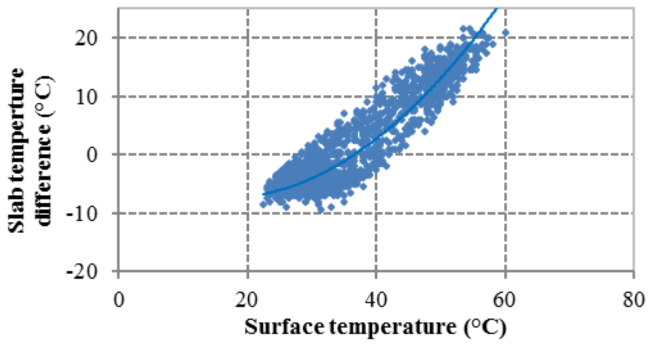



**Fig. 6.** Typical Temperature Differences between the Top and Bottom of the Slab.

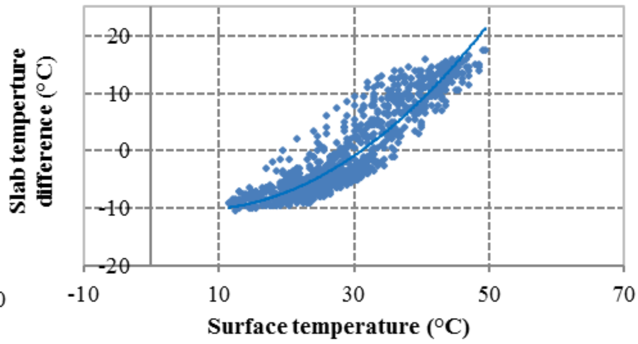
Fig. 7 illustrates the correlation between the surface temperature and the slab temperature difference from May to August and September to November. From the relation, a second-order polynomial equation was developed as shown in Eqs. (4) and (5). The slab temperature difference increases proportionally, as the surface temperature increases. The temperature unit of the formula is in °C and $R^2$ value is 0.784. Using Eqs. (2) through (5), the slab temperature difference of the pavement can be conveniently predicted, based on air temperature obtained from the weather station.

From May to August,

$$Slab\,temp.\,difference = 0.018\times(Surface\,temp.)^2 - 0.584\times(Surface\,temp.) - 2.732 \quad (4)$$




(a) From May to August




(b) From September to November

**Fig. 7.** Correlation between Surface Temperature and Slab Temperature Difference.

From September to November,

$$\begin{aligned} &Slab\,temp.\,difference \\ &= 0.017\times(Surface\,temp.)^2 - 0.225\times(Surface\,temp.) - 9.577 \end{aligned} \tag{5}$$

## Numerical Analysis of Thermal Changes in PCC Pavements

### Modeling of PCC Pavements

Finite element analysis was employed to calculate the temperature gradients of the PCC pavement. The finite element model illustrated in Fig. 8 simulates the pavement section used in field-temperature measurement. The nonlinear finite element package, LS-DYNA [15], was used to compute temperature gradients through the slab thickness. Multiple 8-noded quadratic elements throughout the slab thickness were used to accurately model nonlinear temperature gradients. In this analysis, it was assumed that the slab temperature changes only through its depth. This means that the slab temperature is the same for all nodes with the same depth. All four sides have an insulated boundary condition, and the thickness of subgrade was set to 91.4-cm in order to get enough depth to avoid the interference by the boundary condition. After a series of sensitivity analysis of with different mesh sizes (5.1-cm x 5.1-cm x 2.5-cm, 10.2-cm x 10.2-cm x 5.1-cm, and 20.4-cm x 20.4-cm x 8.5-cm), it was found that mesh size is not affecting on the analysis. For all layers, 10.2-cm×10.2-cm×5.1-cm was chosen to have five layers in the PCC pavement. A three-layer slab was modeled to simulate the variation of temperature gradients in the pavement slab. The 25.6-cm slab is 6.0-m long and 3.9-m wide. Measured material properties of PCC were used for the analysis; a density of 2.36 (g/cm$^3$), a thermal conductivity of 2.48 (W/mK), and a heat capacity of 1.88 (10$^6$ ×J/m$^3$K) [16]. The slab was founded on a 25.6-cm thick crushed limestone base and a 91.4-cm thick subgrade. The density of base and subgrade layer used for the analysis were 1.91 (g/cm$^3$) and 1.73 (g/cm$^3$), respectively. The thermal conductivity and heat capacity of the base and subgrade layer were assumed to be 1.39 (W/mK) and 2.18 (10$^6$ ×J/m$^3$K). The slab was meshed by 39×60×5 and had 11,700 solid elements. The temperature loads are applied on the surface of the pavement, using measured surface temperature every hour; the heat transfers through the slab thickness accordingly.

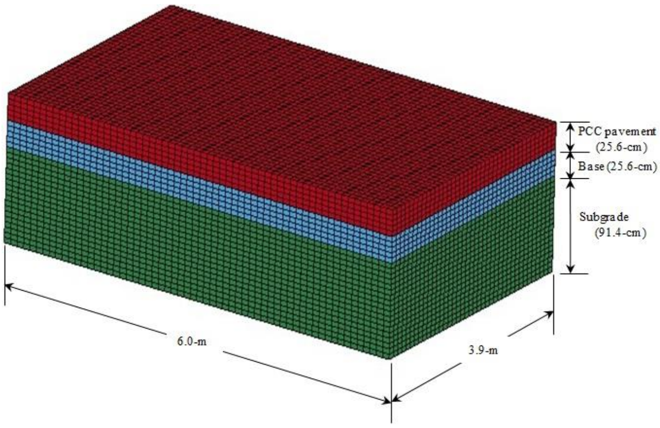
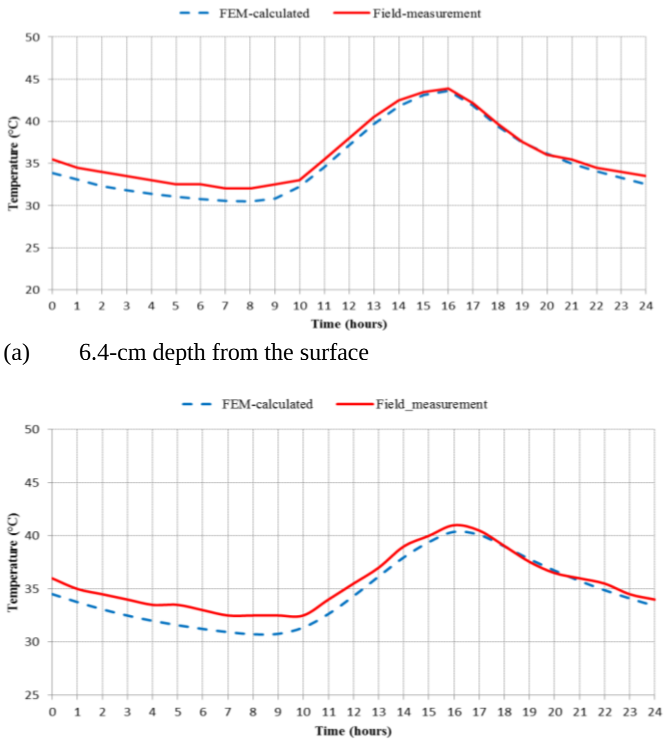



**Fig. 8.** Finite Element Model of the Concrete Pavement Layers.




(a) 6.4-cm depth from the surface

(b) 12.8-cm depth from the surface

**Fig. 1**. Comparison between Field-measured and FEM-calculated Temperature Variation (June 4$^{th}$, 2011).

### Comparison between Measured Temperature Gradients and FEM Results

Fig. 9 shows FEM-calculated 24-hour temperature variations at the 6.4-cm and 12.8-cm depths from the surface of the pavement, together with a comparison of field-measured temperature variations at the same day. As shown in Fig. 9(a), the temperature prediction was reasonably close to the field-measurement. Assuming that the field-measured temperature was exact, the average error of temperature prediction of FEM-calculated data at 6.4-cm depth were around 0.9 % during the peak point during a day (i.e., between 2 p.m. and 4 p.m.), which is an acceptable reliability of accuracy. In Fig. 9(b), the average percentage error increased to 1.4 % between 2 p.m. and 6 p.m., due to the further distance from the pavement surface. This observation presents the validation of FEM analysis to simulate the temperature variation in PCC pavements.

## Local Calibration of EICM

### Climatic Input Data of EICM

Since the EICM was designed and calibrated using nationwide climatic data, it is necessary to perform the local calibration, based on regional climatic patterns and material properties in order to enhance the reliability of the outputs. To predict temperature gradients in the PCC pavement, an analysis was conducted using EICM version 3.4. The cross-section of JPCP used in the field measurement was used for the analysis. The same material properties used in numerical analysis were used in the EICM analysis. Since the MEPDG website provides a climatic data set spanning the period from July 1996 to February 2006 (10 years), the weather station data from both Baton Rouge Airport and Louisiana Agriclimatic Information System (LAIS) were used to create climatic inputs during the same period of field measurements. Two weather stations are marked as white squares and the field location of PCC pavement is marked as a white circle in Fig. 10.

All the climatic data are directly transferred from the weather stations, except the percentage of sunshine and water table. The percentage of sunshine drawn from the weather station data are described as follows: clear, scattered clouds, partly clouds, mostly clouds, overcast. These weather conditions are converted into five discrete numbers (100, 75, 50, 25, and 0 %) in order to directly utilize the numbers as input data in EICM. The water table was obtained from the USGS website [17]. Table 1 shows an example of the climatic input data for 24-hour intervals in EICM.


**Fig. 10.** Locations of Field Site and Weather Stations (Baton Rouge).

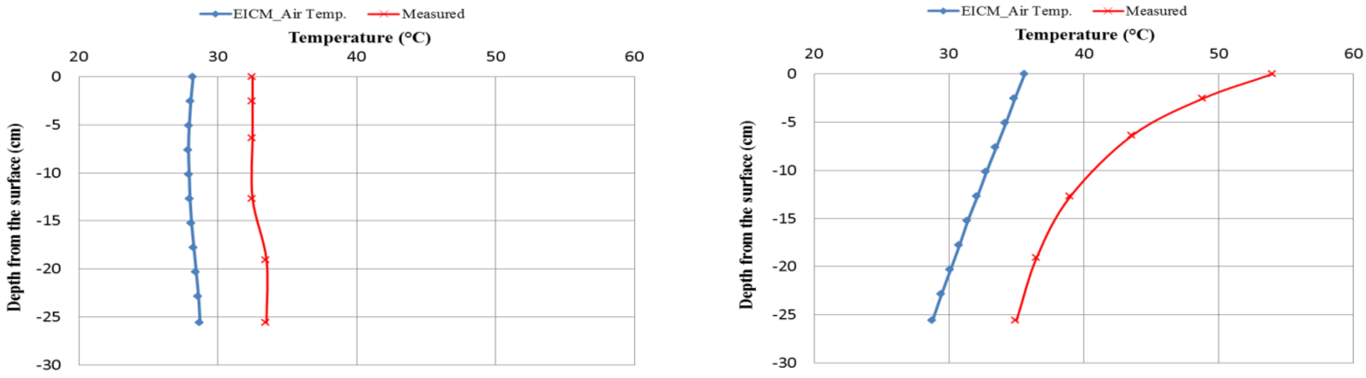
## Calibration of EICM Under Local Climatic Conditions

The EICM analysis was performed using the air temperature obtained from the weather station; the results at 9 a.m. and 2 p.m. are shown in Fig. 11. The EICM results using air temperature (EICM_Air Temp.) do not match well with the measured temperature gradients in the field, although the shape of temperature gradients shows a similar trend. The EICM-predicted temperature underestimates and the field-measured temperature during all time frames. The largest gap between two temperatures occurs on the surface of the pavement at 2 p.m., and the value is 18.3℃. An observation of EICM results revealed that the EICM-predicted temperature (EICM_Air Temp.) at the surface is usually similar to the air temperature value used as an input data in this analysis.

As an effort to better calculate pavement temperature in EICM, the air temperature from the weather station was replaced by the field-measured surface temperature. In the use of the measured surface temperature as input data in EICM, the pavement temperature gradients shifted to the right side, as shown in Fig. 12. The temperature gradients, calculated using surface temperature as input data in EICM (EICM_Surface temp.), provided a better match with the field-measured temperature. Therefore, surface temperature is suitable as input data in EICM to better predict temperature

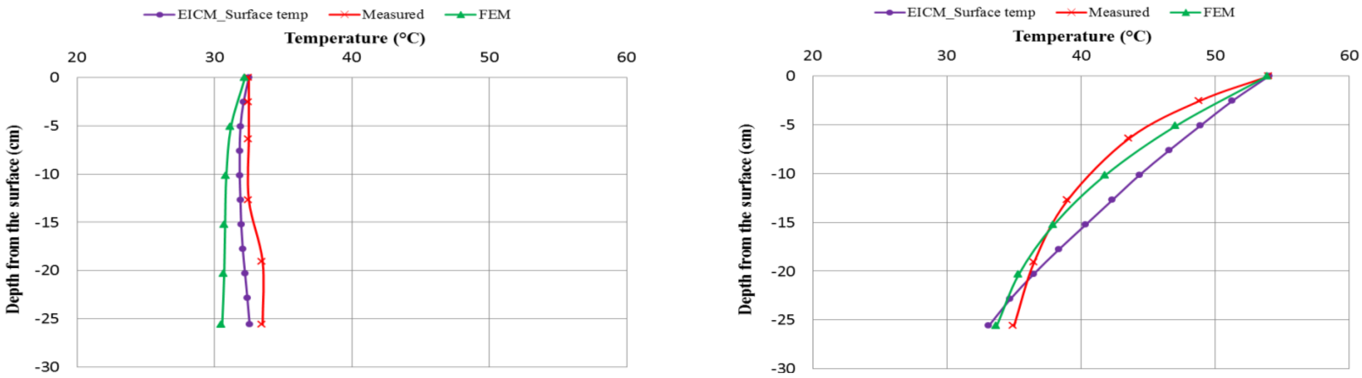
Table 1 Climatic input data in EICM (24-hour intervals).

| Date | Time | Temperature (℃) | Windspeed (km/h) | Sunshine (%) | Precipitation (cm) | Humidity (%) | Watertable (m) |
|---|---|---|---|---|---|---|---|
| 6/1/2011 | 0:00 | 23.3 | 0 | 100 | 0 | 76 | 2.1 |
| | 1:00 | 22.2 | 0 | 100 | 0 | 84 | 2.1 |
| | 2:00 | 22.2 | 0 | 100 | 0 | 87 | 2.1 |
| | 3:00 | 22.2 | 7.4 | 100 | 0 | 87 | 2.1 |
| | 4:00 | 22.2 | 5.6 | 100 | 0 | 91 | 2.1 |
| | 5:00 | 21.7 | 0 | 100 | 0 | 93 | 2.1 |
| | 6:00 | 22.8 | 7.4 | 100 | 0 | 93 | 2.1 |
| | 7:00 | 23.9 | 0 | 75 | 0 | 90 | 2.1 |
| | 8:00 | 26.7 | 7.4 | 100 | 0 | 79 | 2.1 |
| | 9:00 | 28.9 | 7.4 | 100 | 0 | 67 | 2.1 |
| | 10:00 | 31.1 | 7.4 | 100 | 0 | 57 | 2.1 |
| | 11:00 | 33.3 | 11.1 | 100 | 0 | 47 | 2.1 |
| | 12:00 | 35.0 | 14.8 | 50 | 0 | 41 | 2.1 |
| | 13:00 | 35.6 | 13.0 | 50 | 0 | 37 | 2.1 |
| | 14:00 | 36.7 | 11.1 | 75 | 0 | 35 | 2.1 |
| | 15:00 | 36.1 | 9.3 | 75 | 0 | 34 | 2.1 |
| | 16:00 | 37.2 | 22.2 | 75 | 0 | 30 | 2.1 |
| | 17:00 | 37.8 | 0 | 75 | 0 | 29 | 2.1 |
| | 18:00 | 36.1 | 11.1 | 50 | 0 | 39 | 2.1 |
| | 19:00 | 33.9 | 13.0 | 50 | 0 | 47 | 2.1 |
| | 20:00 | 31.7 | 9.3 | 100 | 0 | 53 | 2.1 |
| | 21:00 | 30.6 | 0 | 50 | 0 | 55 | 2.1 |
| | 22:00 | 28.9 | 0 | 50 | 0 | 63 | 2.1 |
| | 23:00 | 28.9 | 5.6 | 25 | 0 | 65 | 2.1 |




(a) 9 A.M. (b) 2 P.M.

**Fig. 11.** Comparison of Temperature Gradients between EICM-prediction with Air Temperature and Field- measurement at Various Times.




(a) 9 A.M. (b) 2 P.M.

**Fig. 12.** Comparison of Temperature Gradients Among EICM-predictions with Surface Temperature, Field- measurement, and FEM-calculation at Various Times.

gradients in the PCC pavement. Eqs. (2) and (3), presented in the previous section, can be used to predict the surface temperature from the measured air temperature at the weather station. Fig. 12 also compares three temperature gradients: a predicted temperature in EICM using surface temperature (EICM_Surface temp.), a field-measured temperature (Measured), and a calculated temperature from finite element analysis (FEM). All three results share the same temperature value on the surface, because a measured surface temperature was used for the boundary condition for all of these. The finite element analysis (FEM) tends to underestimate the temperature gradients in the morning; however, the FEM tends to have a good agreement with the temperature gradients of field-measurement in the afternoon. The temperature gradients calculated from the finite element analysis offer a similar nonlinear trend of field-measured temperature gradients at 2 p.m.

## Conclusions

Temperature was measured in a concrete pavement section (25.6-cm thick) to characterize daily and seasonal temperature fluctuations through the slab thickness. The correlation between air and surface temperatures and surface temperature and slab temperature difference were established based on the measured temperature gradients in the concrete pavement. A local calibration of EICM was performed by comparing EICM-predicted temperature gradients to field measurements. The following observations are drawn from the results of this study:

- The temperature fluctuates at the top surface, yet remains stable on the bottom of the slab during the day. In June, the temperature variation on the surface was 24.5℃, while the temperature variation at the bottom of the slab was 4.3℃.
- The measured surface temperature was much higher than the air temperature collected from the weather station, due to differing procedures in measurement. The temperature difference between surface and air temperature increases remarkably during the daytime; its peak value of 18.4℃ appears at 2 p.m. in June.
- The correlations between the surface and air temperature, as well as the surface temperature and slab temperature difference were developed using second-order polynomial equations. The equations can be used to predict surface temperature or pavement temperature differences from the measured air temperature in Louisiana.

The EICM-predicted temperature gradients using surface temperature as input data show a better agreement with the field-measured temperature gradients. Therefore, the surface temperature, rather than air temperature, is suitable for input data in EICM in order to accurately predict a temperature gradient in PCC pavements in Louisiana.

## Acknowledgments

The authors acknowledge Tyson Rupnow, Shane Laws, and Patrick Icenogle in the Louisiana Transportation Research Center for their assistance in installing the temperature sensors and collecting temperature data. The authors also would like to thank Dr. Jin-won Nam, Assistant Professor at Southern University, for his cooperation in numerical analysis.

## References

1. Huang, Y. H. (2004). *Pavement Analysis and Design*. 2nd ed. Prentice Hall, Inc., New Jersey, USA.
2. Richardson, J.M. and Armaghani, J.M. (1987). Stress caused by temperature gradient in portland cement concrete pavements, *Transportation Research Record*, No. 1121, pp. 7-13.
3. Thompson, M.R., Dempsey, B.J., Hill, H., and Vogel, J. (1987). Characterizing temperature effects for pavement analysis and design, *Transportation Research Record*, No. 1121, pp. 14-22.
4. Choubane, B. and Tia, M. (1992). Non-linear temperature gradient effect on the maximum warping stresses in rigid pavements, *Transportation Research Record,* No. 1370, pp. 11-19.
5. Guo, E.H. and Rice, J.L. (1997). Effects of slab size on critical response in airport concrete pavement, Aircraft/Pavement Technology, In the Midst of Change, *ASCE Proceedings*, Seattle, Washington, USA, pp. 320-334.
6. Heydinger, A.G. (2003). Monitoring Seasonal Instrumentation and Modeling Climatic Effect on Pavements at the Ohio/SHRP Test Road, *FHWA/HO-2003/018*, Toledo, Ohio, USA.
7. ARA, Inc. (2004). Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. NCHRP Project 1-37A, Final Report, Applied Research Association, Inc., ERES Consultants Division, Champaign, Illinois, USA.
8. Climatic Inputs for Mechanistic-Empirical Pavement Design Workshop (2006). Connecticut Department of Transportation, Rocky Hill, CT, USA. http://www.ct.gov/dot/cwp/view.asp?a=1617&q=327668. Accessed July 15, 2011.
9. Climatic data for Mechanistic-Empirical Design of New & Rehabilitated Pavement Structures. NCHRP 1-37. NCHRP. http://onlinepubs.trb.org/onlinepubs/archive/mepdg/climatic_state.htm. Accessed July 25, 2011.
10. Ahmed, Z., Marukic, I., Zaghloul, S., and Vitillo N. (2005). Validation of enhanced integrated climatic model predictions with New Jersey seasonal monitoring data. *Transportation Research Record*, No 1913, pp. 148-161.
11. Zhang, B. and Zhang, J. (2009). Temperature calibration of EICM model in New Mexico. Material, design, construction, maintenance, and testing of pavement, *Proceedings, GeoHunan International Conference*, pp. 93-99.
12. LA DOTD (2006). Standard Specifications for Roads and Bridges, Louisiana Department of Transportation and Development, Baton Rouge, LA, USA.
13. Rasoulina, M., Titi, H., and Martinez, M. (2006). Evaluation of Narrow Transverse Contraction Joints in Jointed Plain Concrete Pavements, *LADOTD/FHWA/06-411*, Louisiana Transportation Research Center, Baton Rouge, LA, USA.
14. Finklin, A.I. and Fischer, W.C. *Weather Station Handbook: An Interagency Guide for Wildland Managers*, http://www.novalynx.com/manuals/nfes-2140.html. Accessed July 15, 2011.
15. Hallquist, J. (1998). *LS-DYNA Theoretical Manual*, Livermore Software Technology Corporation, Livermore, California, USA.
16. Shin, A.H.-C. and Kodide, U. (2012). Thermal Conductivity of Thermal Mixtures for Concrete Pavements, *Cement and Concrete Composites*, 34, pp. 575-582.
17. USGS. Groundwater for US: Active Groundwater Level Network. http://groundwaterwatch.usgs.gov/default.asp. Accessed July 15, 2011.