

Development of Temperature Gradient Frequency Distribution for Kenyan Cement Concrete Pavement: Case Study of Mbagathi Way, Nairobi.

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Abstract
In this paper, it is recognised that the Dutch Design method can be applied in Kenya to develop cement concrete pavements. A major design parameter required for this application is temperature gradient frequency distribution which is still lacking for Kenya, and is the major focus of this paper. The dowel jointed concrete pavement (DJCP) at rehabilitated Mbagathi Way, Nairobi is used as a case study. The limited surface temperature measurements carried out at Mbagathi Way, Nairobi in conjunction with BELLS3 model are used to develop the distribution. The distribution is compared against the default Dutch distribution from which it is seen that the Kenyan distribution has higher values for higher temperature gradient classes. This is, partly, attributed to higher quantities of solar energy in Kenya as compared to the Netherlands.
Keywords: Temperature gradient frequency distribution; BELLS3 model

1. Introduction

Cement concrete roads have been widely applied in other parts of the world. In Africa, experience in these roads is visible in South Africa. In Kenya, the first major concrete overlay was done in the year 2006 – 2007 for the rehabilitation of Mbagathi Way, Nairobi. The 3 km cement concrete road constitutes just 0.002 % of Kenya's road network (http://www.krb.go.ke/Classification.php).

Mbagathi Way is located in Nairobi province, Kenya, 6 km from Nairobi Central Business District. It is a 2-lane dual carriageway which is approximately 3 km long. A rehabilitation of the road was carried out to improve the road and strengthen the pavement. The rehabilitation carried out between 2006 and 2007 led to placement of a 210 mm dowel jointed concrete pavement (DJCP) on 40 – 90 mm dense bitumen macadam (DBM) base, 300 mm hand packed stone (HPS) sub-base, 50 mm gravel working platform, 300 mm improved sub-grade, and *in situ* black cotton subsoil. This dowel jointed cement concrete layer was designed by applying [3]cncPAVE modelling programme developed and applied in South Africa.

The rehabilitation of Mbagathi Way has put forward a study area on which researches can be done to perfect the development of roads in cement concrete in a localised manner to suit the Kenyan situation. In an MSc thesis research (Jangaya 2010), it was identified that the Dutch design method could be applied in Kenya comfortably. It was also identified that to incorporate the climatic effects, concrete road temperature gradient frequency distribution had to be developed to be incorporated in the [4]VENCON2.0 programme.

1.1. Temperature Gradient Frequency Distribution Determination in the Netherlands

In the Netherlands, the temperature gradient was continuously measured on a stretch of motorway in the centre of the Netherlands in the years 2000 and 2001. The (continuously reinforced) concrete pavement had a thickness of 250 mm and the measurements were done before the porous asphalt wearing course was constructed. Based on these measurements, a default temperature gradient frequency distribution (Table 1), was developed and incorporated in the current Dutch design procedure (Houben *et al.* 2006).

[3] cncPave is a computer simulation program whose purpose is to facilitate competent decision-making when designing concrete pavements. The programme is developed by the Cement and Concrete Institute of South Africa
[4] VENCON2.0 is a software in which the Dutch design procedure has been packaged

Table 15: Default temperature gradient frequency distribution in the Netherlands

Temperature gradient class (^{0}C/mm)	Average temperature gradient, ΔT (^{0}C/mm)	Frequency distribution, ($\%$)
0.000 – 0.005	0.0025	59
0.005 – 0.015	0.01	22
0.015 – 0.025	0.02	7.5
0.025 – 0.035	0.03	5.5
0.035 – 0.045	0.04	4.5
0.045 – 0.055	0.05	1.0
0.055 – 0.065	0.06	0.5

In the case of this research work, it was only practical to carry out these measurements for a limited number of days on the 210 mm thick (dowel jointed) concrete road at Mbagathi Way, Nairobi to help develop a temperature gradient frequency distribution that is the main objective of this paper.

2. Methods and Materials

Pavement surface temperature measurements were done on 25th and 26th May, 25th and 26th June, 26th and 27th July, and 23rd and 24th August, 2010. The surface temperature measurements were taken next to Medina Centre Mosque (Chainage Km 2+380), Fig. 1. A non-contact infrared digital thermometer Model 72 – 823, Fig. 2 was used to carry out the measurements. The surface was illuminated for a minute for each measurement. For the 07:07.5 hrs recording, measurement was done as from 07:07 hrs to 07:08 hrs.

Fig. 1: Location where the surface temperature measurements were done

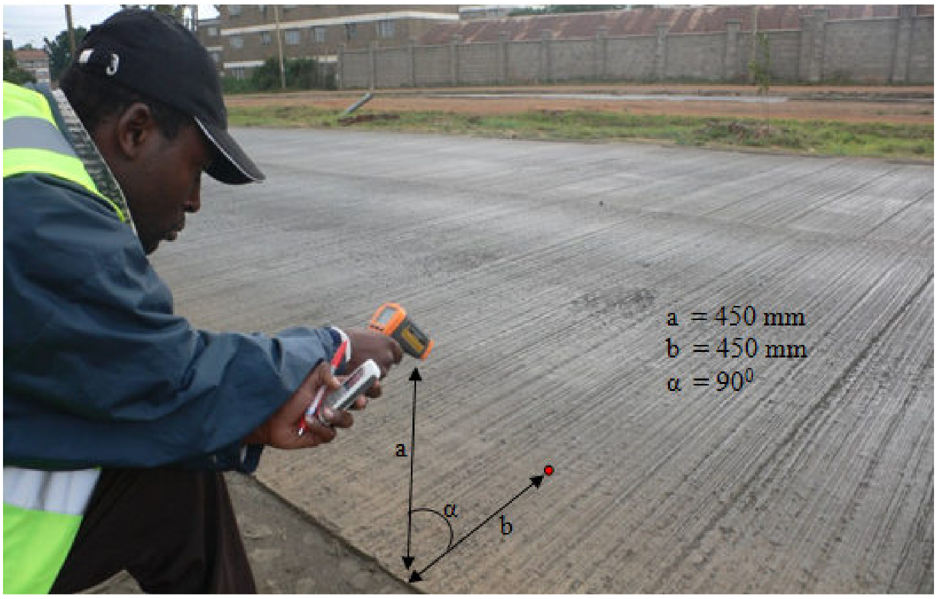

Fig. 2: Temperature measurement in progress

Average pavement surface temperatures were recorded with time intervals of 15 minutes with the first measurement taken at 07:07.5 hrs and the last at 18:52.5 hrs. The results are shown in Appendix A.

To determine the corresponding temperatures at the base of the pavement, the average surface temperatures obtained were entered in BELLS3 temperature model (Appendix B) after consideration of three probable temperature models (Balbo & Severi 2002, ASTM International 2006). The surface temperatures, in ^{0}C, were entered in the BELLS3 model together with time of day, in 24 hour clock system; distance below the surface where the temperature is to be calculated (in this case 210 mm), in mm; and average air temperature of the previous day, in ^{0}C. The average air temperatures for the previous days to the measurement dates were read from the records from Kenya Meteorological Department, Nairobi. The temperature differences between the top and bottom of the concrete slab were divided by the slab thickness (210 mm). This resulted in a linear temperature distribution with a constant temperature gradient distribution. The temperature gradient frequency distribution obtained by using the BELLS3 equation were corrected to cater for the period 19 hrs to 07 hrs. This correction was done with consideration of the night HV traffic being taken as 40% of the day traffic and the assumption that for the period 19 hrs to 07 hrs the temperature gradient is smaller than 0.005 ºC/mm. All negative temperature gradients are assigned, similar to the Dutch procedure, to the temperature gradient class 0 – 0.005 ºC/mm.

3. Results and Discussion

When considering a whole day, the correction for the night traffic led to an increase of the frequency of occurrence of the temperature gradient class 0 – 0.005 ºC/mm and a reduction of the frequency of occurrence for all the other classes. The frequency of occurrence of the temperature gradient class 0 – 0.005 ºC/mm is equal to (40/140)*100% + (100/140)*11.7% = 36.9%. For all the other temperature gradient classes, due to the night traffic, the uncorrected frequency of occurrence needs to be multiplied by the factor 100/140 = 0.714. Both the uncorrected temperature gradient frequency distribution, based on the field measurements between 07 hrs and 19 hrs, and the corrected temperature gradient frequency distribution for the whole day are presented in Table 2.

Table 16: Temperature gradient frequency distribution, Mbagathi Way, Nairobi

Temperature gradient class, ^{0}C/mm	Average temperature gradient, ^{0}C/mm	Uncorrected frequency distribution between 07 and 19 hrs, %	Corrected frequency distribution for whole day, %
0.000 – 0.005	0.0025	11.7	**36.9**
0.005 – 0.015	0.01	33.0	**23.7**
0.015 – 0.025	0.02	13.9	**9.9**
0.025 – 0.035	0.03	12.7	**9.1**
0.035 – 0.045	0.04	8.6	**6.1**
0.045 – 0.055	0.05	11.5	**8.2**
0.055 – 0.065	0.06	8.6	**6.1**

Table 17: Temperature Gradient Frequency Distribution: the Netherlands and Kenya

Temperature gradient class, ^{0}C/mm	Average temperature gradient, ^{0}C/mm	Frequency distribution , %	
		Netherlands	Mbagathi Way, Kenya
0.000 – 0.005	0.0025	59	36.9
0.005 – 0.015	0.01	22	23.7
0.015 – 0.025	0.02	7.5	9.9
0.025 – 0.035	0.03	5.5	9.1
0.035 – 0.045	0.04	4.5	6.1
0.045 – 0.055	0.05	1.0	8.2
0.055 – 0.065	0.06	0.5	6.1

The distribution is compared against the default Dutch distribution (Table 3) from which it is seen that the Kenyan distribution has higher values for higher temperature gradient classes. This is, partly, attributed to higher quantities of solar energy in Kenya, located around the equator, as compared to the Netherlands, located around latitude 52 degrees north.

4. Conclusion

A more comprehensive temperature gradient distribution can be developed. Going by the Dutch time frame, a two year continuous temperature measurements can be done and temperature measurements carried out for more points along the height of the pavement unlike for the pavement surface as used in this research work.
The BELLS3 model applied is meant for asphalt pavement and not concrete pavement. The nature of asphalt pavement being darker in colour as compared to concrete surface could lead to overestimation of the values calculated.

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References

1. ASTM International (2006), “Standard test method for prediction of Asphalt-Bound Pavement Layer Temperatures”, *Report* no. D7228-06a, United States
2. Balbo, J. T., Severi, A. A. (2002), “Thermal gradients in concrete pavements in tropical environment: an experimental appraisal”, *Transportation Research Record* n^o 1809, TRB, pp 12-22, Washington, D. C.,
3. Houben, L. J. M. (2006), “Backgrounds of VENCON2.0 Software for the Structural Design of Plain and Continuously Reinforced Concrete Pavements”, Delft University of Technology, the Netherlands
4. Jangaya, P. O. (2011), “Evaluation of Concrete Pavement Design Procedures: A Case Study of the Rehabilitation of Mbagathi Way, Nairobi, Kenya”, *MSc thesis*, Moi University, Kenya.
5. Ministry of Roads, Materials Testing and Research Department (2002), “Pavement Evaluation Report for Mbagathi Way”, *Report* no. MB 665, Kenya.
6. Siyenza Engineers (2005), “Mbagathi Way Rehabilitation Project, Dowel Jointed Concrete Pavement”, (Rev 1)

Appendices

Appendix A: Pavement surface temperatures

The DJCP surface at Mbagathi Way, Nairobi was measured by means of an infrared non-contact thermometer. These measurements were carried out during the day as 07:07.5 hrs to 18:52.5 hrs, with intervals of 15 minutes, on 25th and 26th May, 25th and 26th June, 26th and 27th July, and 23rd and 24th August, 2010. A time span of 1 minute was allowed for each measurement. The information is presented graphically in Figures 3, 4, 5 and 6 for the months May, June, July and August, 2010, respectively.

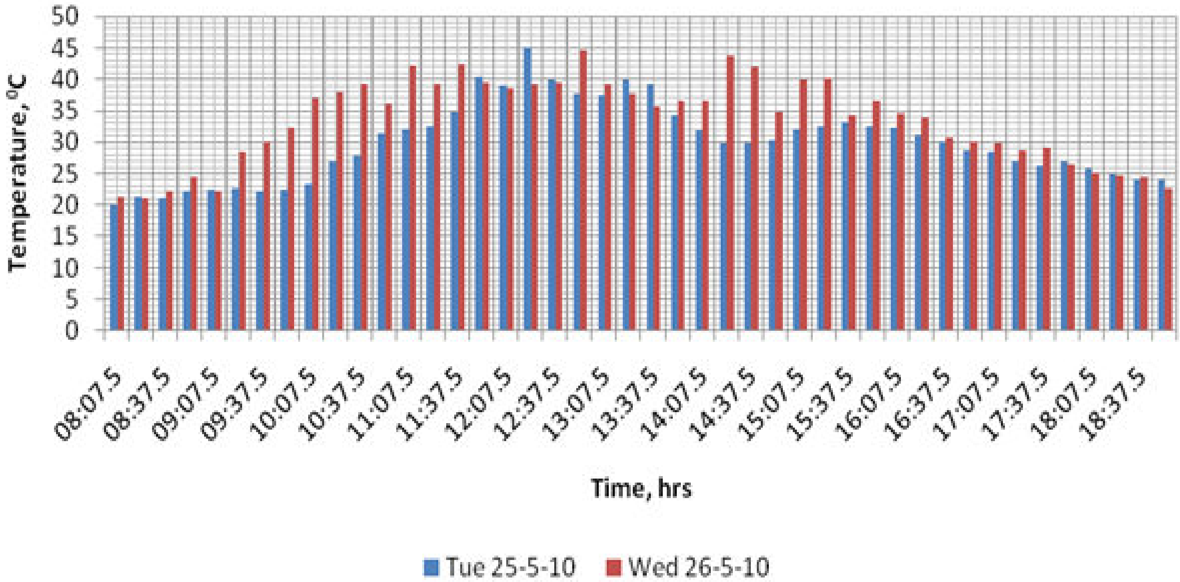

Figure 3: Temperature measurements data collected in May, 2010

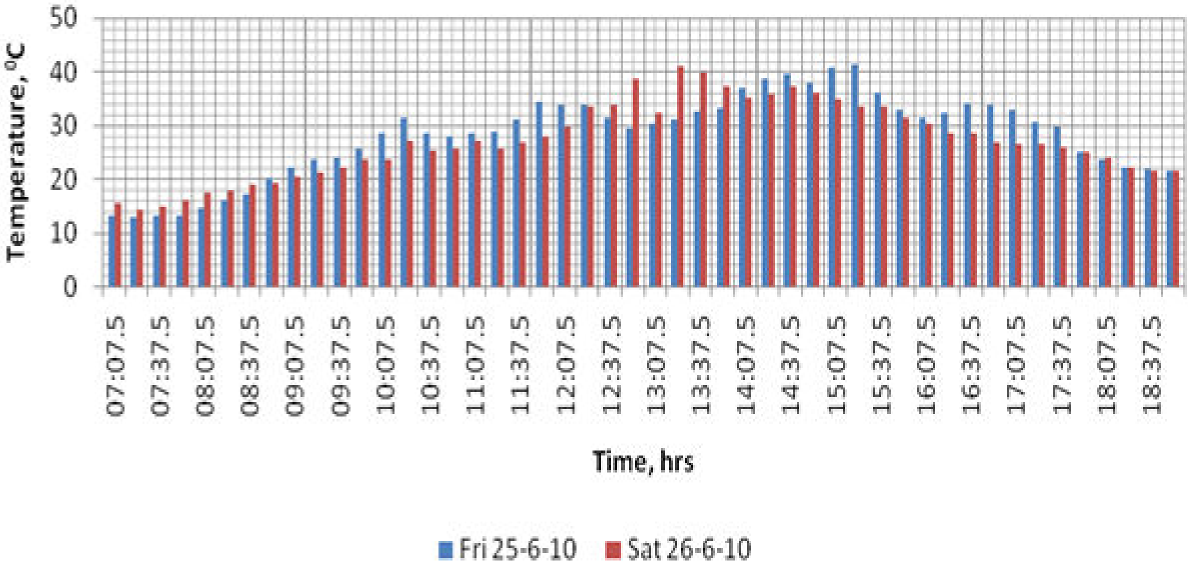

Figure 4: Temperature measurements data collected in June, 2010

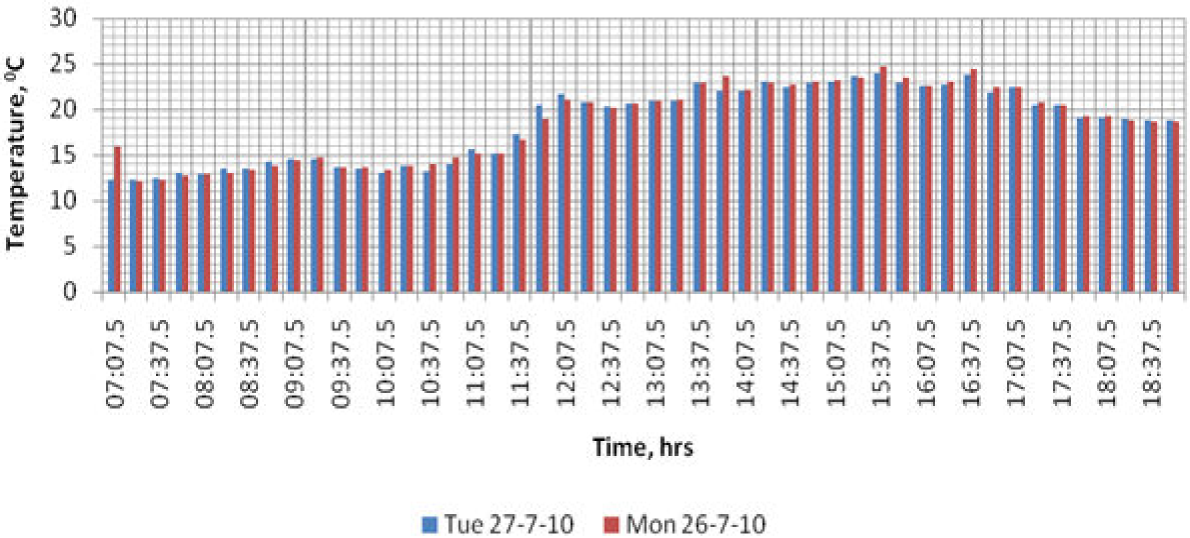

Figure 5: Temperature measurements data collected in July, 2010

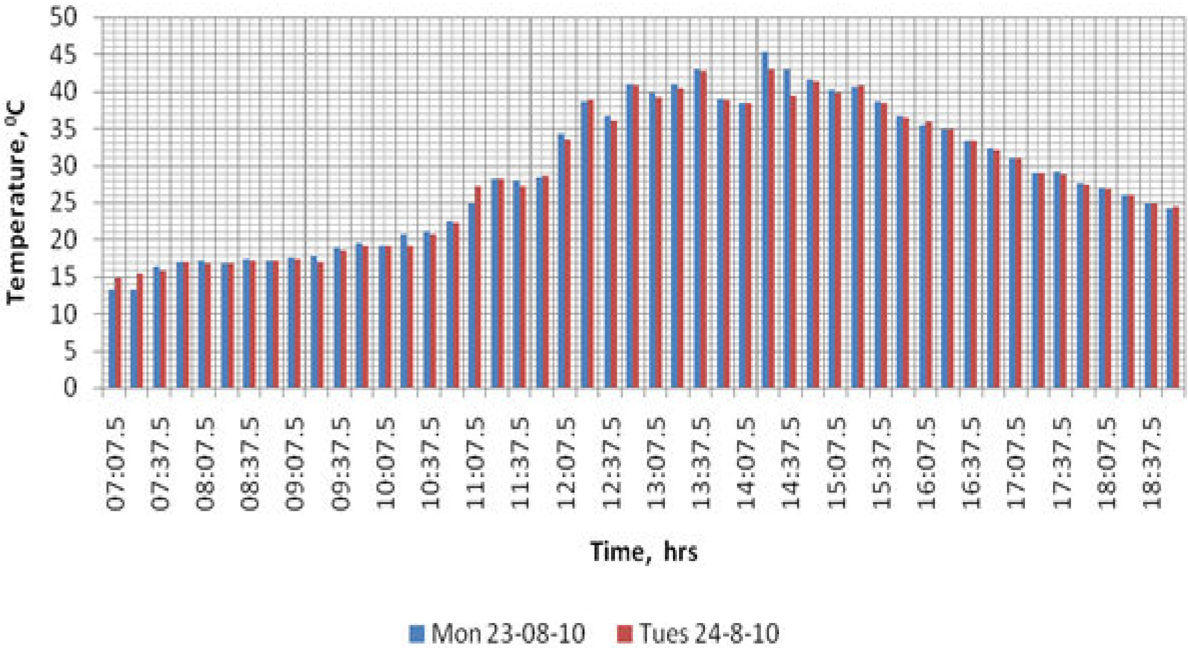

Figure 6: Temperature measurements data collected in August, 2010

Appendix B: BELLS3 temperature model

In determining the corresponding temperatures at the base of the CC pavement, two temperature models (one for cement concrete roads, and two for asphaltic concrete roads) were considered. With these models it was possible to obtain the temperature at the base of the concrete layer. For the BELLS models, the pavement surface temperature (at top of surface) is measured by use of non-contact infrared digital thermometer. The BELLS model is then applied to determine the temperatures at the base of the concrete layer. A linear temperature frequency distribution is then developed.

BELLS Equations

Two models for temperature profiles, the so called BELLS equations (ASTM International 2006) are presented. Both of them were developed for use in asphalt concrete pavements. One is for use with Long-Term Pavement Performance (LTPP) protocol testing and the other for routine testing. The difference between the two is that the LTPP protocol testing model accounts for the time it takes to conduct each Falling Weight Deflectometer (FWD) test and move forward to the next test location. During this period, the pavement surface where the temperature is measured with the FWD's Infrared (IR) sensor has been shaded for five to six minutes. The shading allows the surface to cool, particularly on sunny days. The LTPP data used to develop the BELLS model was collected under such shading conditions. FWD tests conducted routinely by most highway agencies typically require the equipment to be on a specific test location for a minute or less, resulting in much less cooling of the pavement surface. To adjust for cooling, the LTPP surface temperature data was adjusted upward by different amounts, depending on the amount of cloud cover. This "shade adjusted" data was used to develop another BELLS model that is more suited for routine testing. The "shade-adjusted" model is referred to as BELLS3 (Eqn. 1).

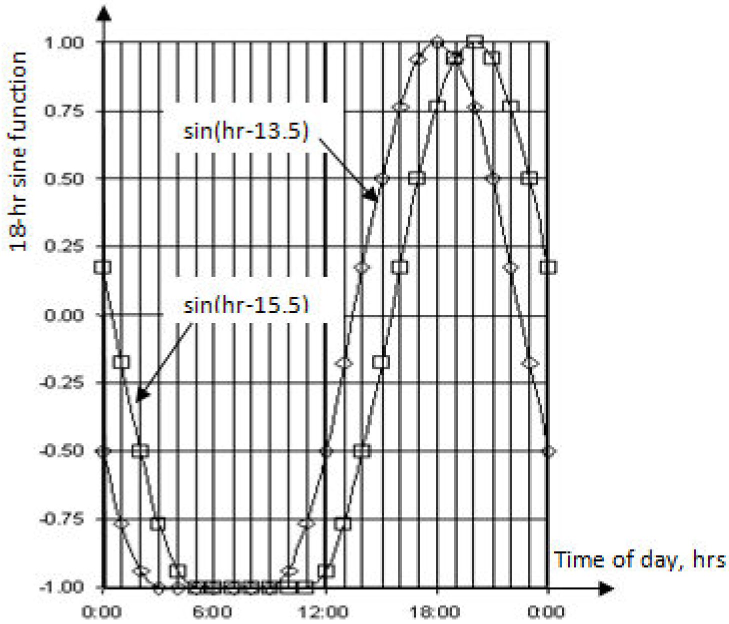

Figure 7: 18-hr Sine Function in BELLS Equations

Four data items are needed to calculate temperature at depth using BELLS equations. These items are: surface temperature, in ^{0}C; time of day, in 24 hour clock system; distance below the surface where the temperature is to be calculated, in mm; and average air temperature of the previous day, in ^{0}C.

BELLS3 temperature model

$$T_d = 0.95 + 0.892T_s + \{\log(d) - 1.25\} * \{-0.448T_s + 0.621T_t + 1.83 * \sin(hr_{18} - 15.5)\} + 0.042T_s * \sin(hr_{18} - 13.5) \quad (1)$$

When using the sin(hr_{18} - 15.5) (decimal) function, only use times from 11:00 to 05:00 hours. If the actual time is not within this time range, then calculate the sine as if the time was 11:00 hours (where the sine = -1). If the time is between midnight and 05:00 hours, add 24 to the actual (decimal) time. Then calculate as follows: If the time is 13:15, then in decimal form, 13.25 - 15.50 = -2.25; -2.25/18 = -0.125; -0.125 x 2 π = -0.785 radians; sin(-0.785) = -0.707. (Note that an 18-hr sine function is assumed, with "flat" negative 1 segment between 05:00 and 11:00 hours as shown in Fig. 7).

When using the sin(hr_{18} - 13.5) (decimal) function, only use times from 09:00 to 03:00 hours. If the actual time is not within this time range, then calculate the sine as if the time is 09:00 hours (where the sine = -1). If the time is between midnight and 03:00 hours, add 24 to the actual (decimal) time. Then calculate as follows: If the time is 15:08, then in decimal form, 15.13 - 13.50 = 1.63; 1.63/18 = 0.091; 0.091 x 2 π = 0.569 radians; sin(0.569) = 0.539. (Note that an 18-hr sine function is assumed, with "flat" negative 1 segment between 03:00 and 09:00 hours as shown in Fig. 7).

BELLS3 model was applied in this research work as the pavement surface temperature could be measured safely for a shorter time compared to BELLS2 model. The road was constantly being trafficked, and there was high risk of being run down by the moving vehicles.