

Development of Innovative Techniques for the Instrumentation of Composite and Wet on Wet Pavement Sections at MnROAD

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Abstract

Composite and wet on wet concrete pavements are a promising solution for the economical, sustainable and durable construction and renewal of highways. Wet-on-wet pavements consist of Portland cement concrete (PCC)-over-PCC, with a relatively thin PCC layer placed wet on a wet thicker layer made of a less expensive PCC mixture. A composite pavement here will be referred to as, a relatively thin hot mix asphalt (HMA) layer placed over a less expensive PCC mixture. In order to acquire knowledge on the performance of these pavements, three heavily instrumented pavement sections were constructed at the Minnesota Road Research Facility (MnROAD) in May 2010. The purpose of the instrumentation is to establish the magnitude of the environmental loads that develop within these pavements and the response of the pavement to both these environmental loads as well as traffic loads. Without this, the development of a rational mechanistic-empirical design process is not possible. The instrumentation of PCC pavements constructed in two lifts has never been performed before and presents a surmountable challenge. Discussed below are novel instrumentation techniques that were developed to overcome these challenges.

Introduction

Composite and wet on wet pavements are a promising solution for the economical, sustainable and durable construction and renewal of highways. Wet on wet pavements consist of two-layer paving, namely Portland cement concrete (PCC)-over-PCC, with a relatively thin PCC layer placed wet on a wet, thicker layer constructed of a less expensive PCC mixture. A composite pavement here will be referred to as a relatively thin hot mix asphalt (HMA) layer placed over a less expensive PCC mixture.

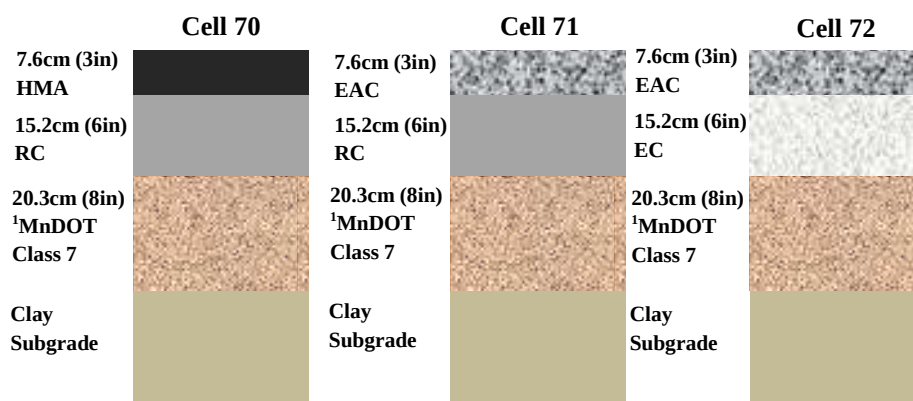
There are several advantages in using these pavement systems for the construction of highways. First, the project cost can be reduced by using high-quality aggregates only in the surface wearing course, while using less expensive aggregates that are locally available for the lower course. Costs saved by using the less expensive mix for the lower layer allows for the placement of a more expensive, higher quality wearing course for the upper layer with more skid-resistance and less noise. Sometimes the lower layer will consist of a concrete containing recycled concrete aggregate (RCC) from an existing pavement being reconstructed. This is a sustainable rehabilitation technique that utilizes materials and resources already invested in a pavement being reconstructed.

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In the United States, there have not been many PCC-over-PCC projects carried out in the past decades, except for some experimental sections in Michigan and Kansas that were constructed in the 1990's. On the other hand, in many European countries, such as the Netherlands, Germany and Austria, two-layer composite pavements are constructed as a part of standard paving practice (1). More wide spread adoption in the United States has been inhibited, in part, due to the limited experience within most state highway agencies in the design and construction of these pavements.

Research Significance To accurately predict the design life of a wet-on-wet or composite pavement, the temperature and moisture gradients that develop within the slabs must be accurately quantified. Much work has gone into quantifying the magnitude of the temperature and moisture gradients that develop in traditional jointed plain concrete pavements (JPCPs). However, the magnitude of the temperature and moisture gradients and the resulting stress that develop in these pavements is not well known. The Minnesota Road Research Facility (MnROAD) constructed three different composite pavement test sections. The impetus for constructing these test sections is to establish a better understanding of how to construct composite pavements but also to characterize the magnitude of the environmental loads that develop in these structures as well as the response of these pavements to these loads. All three sections were heavily instrumented using innovative installation techniques that were developed. The focus here will be on providing a detailed description on how the instrumentation of the climatic and static strain gages was performed. Some of the temperature and moisture data collected over the first year using this instrumentation will then be presented and the temperature and moisture distributions that develop will be characterized and compared. A detailed analysis on the response of these structures, as measured using the static strain gages, to these climatic loads was performed and the results can be found elsewhere (2).

MnROAD Composite Sections MnROAD is the world's largest outdoor pavement laboratory and is located near Albertville, MN, USA which is approximately 65 km northwest of Minneapolis, MN (3). These pavement sections constructed at MnROAD consist of (i) a HMA layer over a concrete layer with recycled concrete aggregate (RC) layer (Cell 70), (ii) a PCC layer with exposed aggregate (EAC) over a RC layer (Cell 71), and (iii) an EAC layer over an economical concrete (EC) layer (Cell 72). Additional information regarding the mixture designs used to construct each layer can be found in reference (5). These three structures are shown in Figure 1. The composite pavements with a PCC surface layer have 4.6-m joint spacings with two 3.7-m lanes.



¹MnDOT Class 7 base is a densely graded unstabilized base (4).

Figure 1. Composite pavements constructed at MnROAD.

Instrumentation of MnROAD Composite and Wet-on-Wet Sections The three experimental cells constructed are heavily instrumented with a variety of sensors capable of measuring temperature, relative humidity, and static and dynamic strain at multiple locations and depths within each pavement structure. In addition, a weather station is also located on site to capture all primary climate indicators. Each cell has two slabs instrumented with temperature and moisture sensors for replication. The details regarding other sensors and their installation can be found in (5).

The instrumentation of the upper EAC layer for Cells 71 and 72 was quite challenging since the sensors in the upper layer need to be installed after the placement of the first layer and before the placement of the second layer. Any sensors that are higher than the depth of the first layer would be taken out by the pan of the paver as the first layer is being placed. Moreover, the amount of time between the placement of the first and second layer is restricted to less than 30 minutes to ensure bonding between the two layers.

The other challenge with the sensor installations in the upper layer is that each of these sensors has lead wires that need to be wired into the data loggers prior to paving so that data can be collected as the concrete is being placed. To avoid being damaged by the track of the paver, the lead wires for the sensors to be installed in both the upper and lower layers need to be buried underground prior to the passing of the paver. This can be seen in Figure 2. Therefore, the sensors to be installed in the upper layer must be temporarily stored in the lower layer as it is being paved.

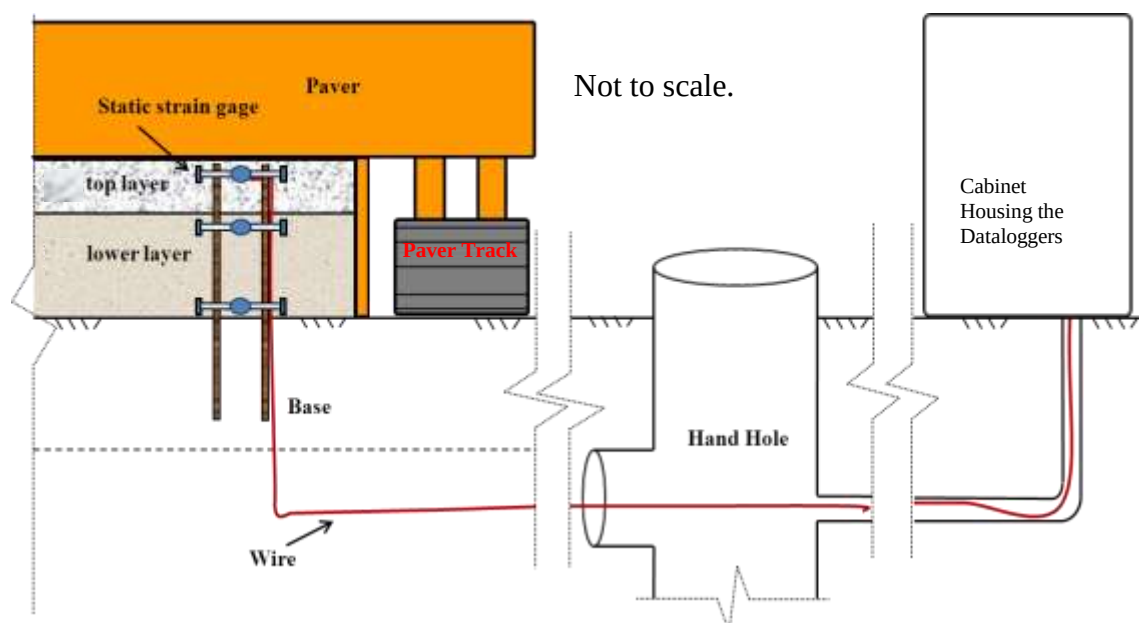


Figure 2. Sensor wire path to data collection cabinet.

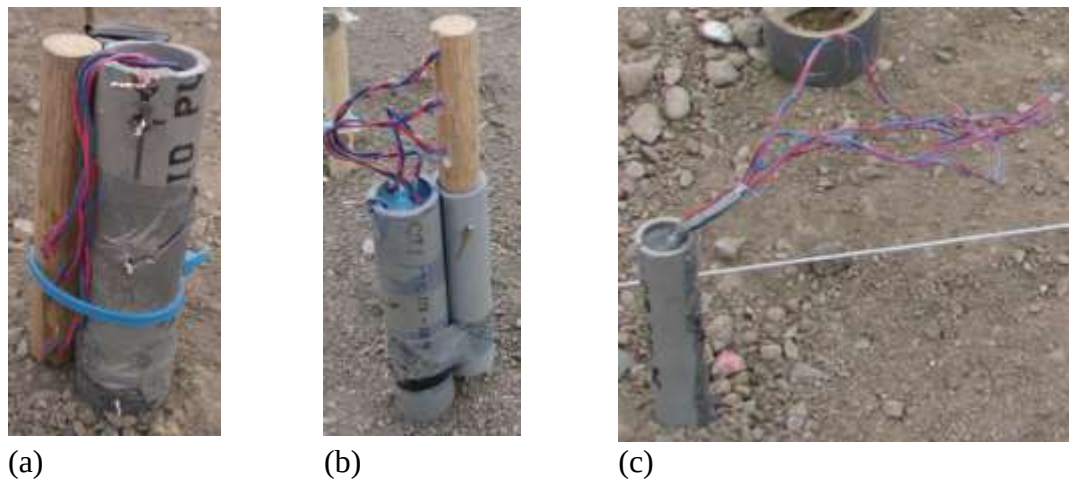
The easiest way to instrument these pavements is to install the sensors in the lower layer before paving and then to retrofit sensors in the upper layer after paving. Unfortunately, it is not a viable option for this project because this would prevent the collection of climatic and static strain data in the upper concrete layer as the concrete hardens. Therefore, innovative installation techniques had to be developed for installing the sensors in the upper layer prior to paving the layer. Descriptions of the temperature and moisture sensors and the static strain gages installed and the installation techniques developed are provided below.

Temperature Sensors Omega Type T Special thermocouples (TCs) were installed throughout the depth of the pavement structure so that temperature could be measured to an accuracy of $\pm$ the greater of 0.4 percent or 0.5°C . Figure 3 shows a typical TC installation for these composite sections. As can be seen, holes were drilled into a polymerized vinyl chloride (PVC) pipe at various depths so that the TC junction could be extended through the pipe wall. After the TC wires were in place, the PVC pipe was filled with epoxy so that the wires would not move during the paving process and that the rigidity of the PVC pipe was more similar to that of the concrete.

TCs installed in the upper concrete layer for Cells 71 and 72 were attached to a wood dowel that is eventually placed in a holder attached to the side of the PVC pipe. See Figures 3(a) and 3(b). Before the passing of the first paver, the dowel is anchored to the PVC pipe with cable ties, as shown in Figure 3(a). A piece of electric tape is placed over the top of the holder to ensure it is not filled with concrete when the first paver passes. After the passing of the first paver, each sensor is located in the first layer of PCC and the cable tie is cut. Then, the wood dowel is placed in the holder attached to the side of the PVC pipe, as shown in Figure 3(b). A screw is driven through the holder and into the dowel to secure it in place before the second paver passes. Cable ties are attached to each dowel so that the tie extends outward above the elevation of the first layer of concrete so the sensor locations are easily identified after the passing of the first paver, as seen in Figure 4.

For Cell 70, the TCs to be installed in the HMA layer are not attached to a dowel, as seen in Figure 3(c). The group of loose wires is pulled to the surface of the

PCC layer right after the paver passes. Once the HMA layer is placed, a core is pulled from this layer near these installations so that the group of loose wire can be drawn up through the core hole. They are then installed in the HMA at predetermined depths.



(a) (b) (c)
Figure 3. TCs installed. (a) Installation prior to the passing of the first paver, (b) Position where the dowel would be when the second paver passes, and (c) Installation in Cell 70.

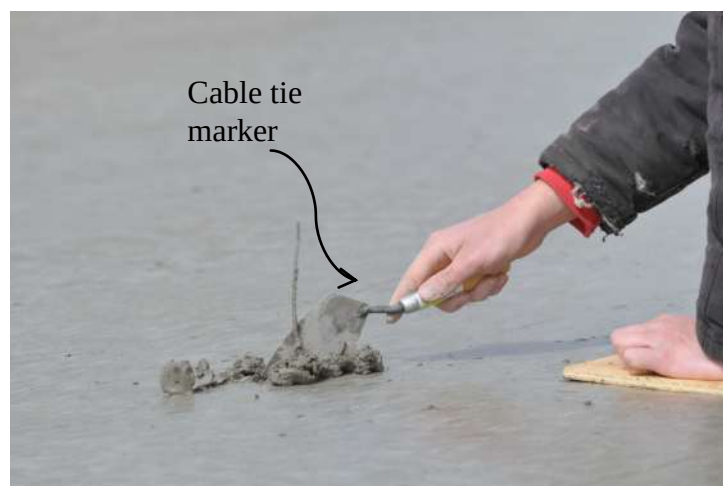


Figure 4. Cable ties attached to the dowel so that the sensor locations could be easily located.

Concrete Moisture Sensors

In order to measure moisture within the concrete, Sensirion SHT75 (6) relative humidity/temperature (MC) sensors were installed. The resolution of this sensor is $\pm 2\%$ at relative humidities between 10 and 90%. Each sensor is fed up through a PVC pipe, as was done for the installation of the TCs. The sensors are pulled through holes drilled into the wall of the PVC pipe and protective capsules were then mounted on the outside of the PVC pipe over the sensor. See Figure 5. These sensors are easily damaged and therefore must be encapsulated in such a way that the water vapor is permitted to reach the sensor, while still protecting the sensor from coming into contact with the fresh concrete.

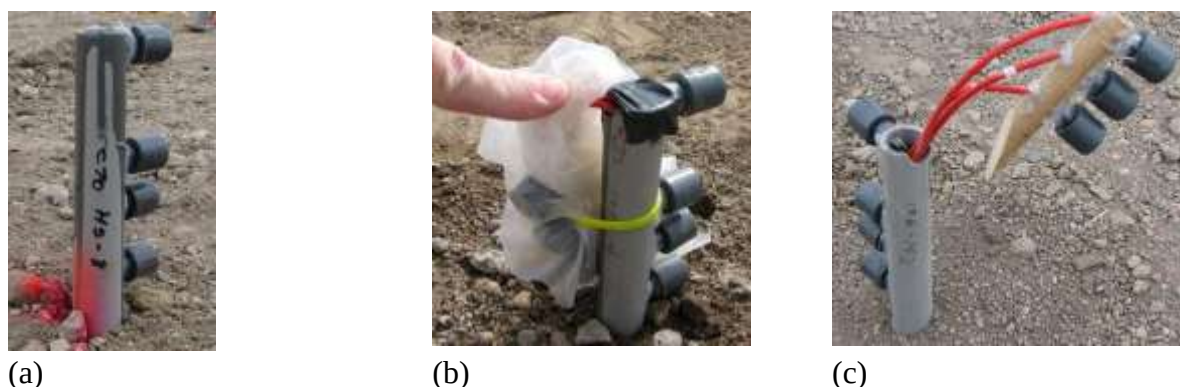


Figure 5. Concrete RH sensors installed (a) Installation in Cell 70.

(b) Installation just prior to the passing of the first paver, and (c) Sensors to be installed in the upper and lower PCC layers.

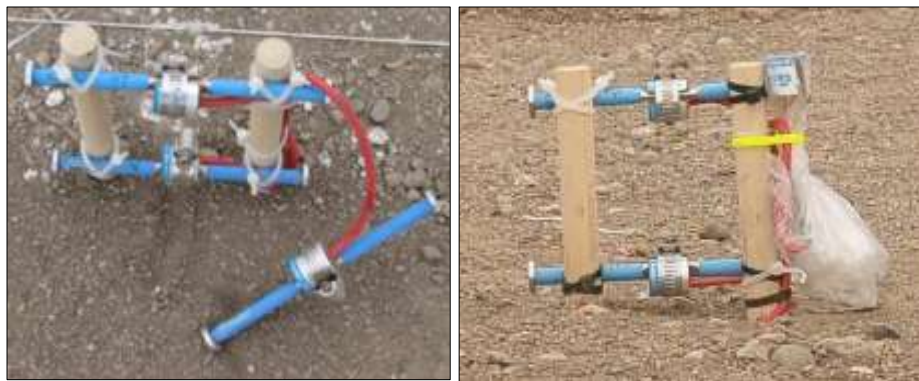
In Cell 70, the moisture sensors were installed in the lower PCC layer (Figure 5(a)) but not the upper HMA layer, while in Cells 71 and 72 the moisture sensors were installed in the upper and lower PCC layers. An example of the installations for Cells 71 and 72 is shown in Figures 5(b) and 5(c). The lower portion of the installation for these cells is the same as is used for Cell 70 except three additional sensors are pulled through the PVC pipe and attached to a wood dowel, as seen in Figure 5(c). These sensors are installed in the upper PCC layer. Holes are drilled through the dowel and then the sensors are pulled through these holes. Protective capsules are then placed over the sensors and mounted to the dowel. The end of the dowel is cut on an angle so that the depth the dowel is wedged into the PVC pipe can be controlled. A screw is then driven through the PVC pipe and into the dowel to lock it into place before the passing of the second paver. To protect the sensors mounted to the dowel as the first paver passes over them, they are wrapped in plastic and anchored to the PVC pipe with cable ties, as shown in Figure 5(b). During paving, the sensors are stored in the bottom concrete layer until after the passing of the first paver. The cable tie is cut, the plastic is removed and then the dowel is installed in the PVC pipe before the passing of the second paver.

Static Strain Gages The PCC response to static environmental loads is measured using Geokon Model 4200 vibrating wire (VW) strain gages. The sensor is also equipped with a thermistor so corrections for temperature can be made. The resolution of the strain gage is ± 1 microstrain with the accuracy of the thermistor being $\pm 0.35^\circ\text{C}$.

Figure 6 (a) shows a typical installation setup for the vibrating wire gages in Cell 70. For Cells 71 and 72, each installation location includes two VW gages in the lower PCC layer, as is done for Cell 70, along with one additional sensor in the upper PCC layer, as shown Figure 6 (b). Before paving the lower layer, the cylindrical housing containing the plucker and thermistor portion of the vibrating wire gage is removed from the hollow tube portion of the gage. The housing is then covered with plastic and cable tied to the lower wooden dowel rod, as shown in Figure 6. The hollow tube is attached to two dowels that will be used to extend the dowels on which the lower two gages are hung into the second layer of concrete. Couplings are glued and screwed to the bottom of the two extensions so that the extension can be easily attached to the existing dowels after the placement of the first layer of concrete. The extensions are customized individually for each installation to be sure the final depth and location of the sensor is correct.



a.) Cell 70.



b.) Cells 71 and 72

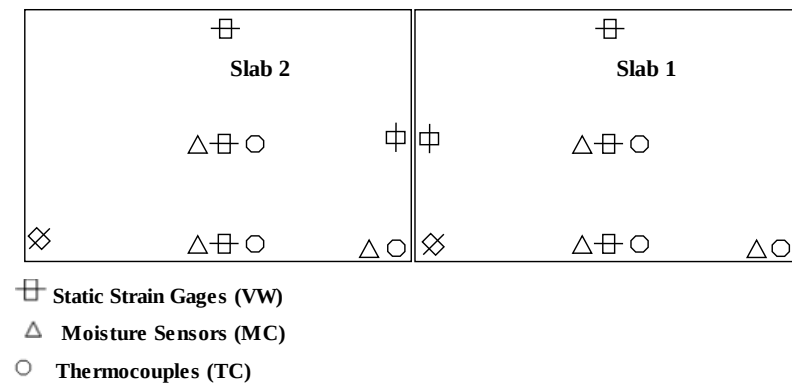
Figure 6. Static strain gage installations.

After the first paver passes, the sensors are located within the bottom layer of concrete. The cylindrical housing is cut free from the dowel and the protective plastic sheet is removed. The housing is then reattached to the hollow tube/extension assembly using a hose clamp. The couplings on each dowel end of the extension assembly are then fitted on top of the dowels in the lower layer of concrete. A screw is driven through the coupling and into the dowel to lock it into place before the top layer of concrete is placed. The installation of the hollow tube/extension assembly after the passing of the first paver can be seen in Figure 7.

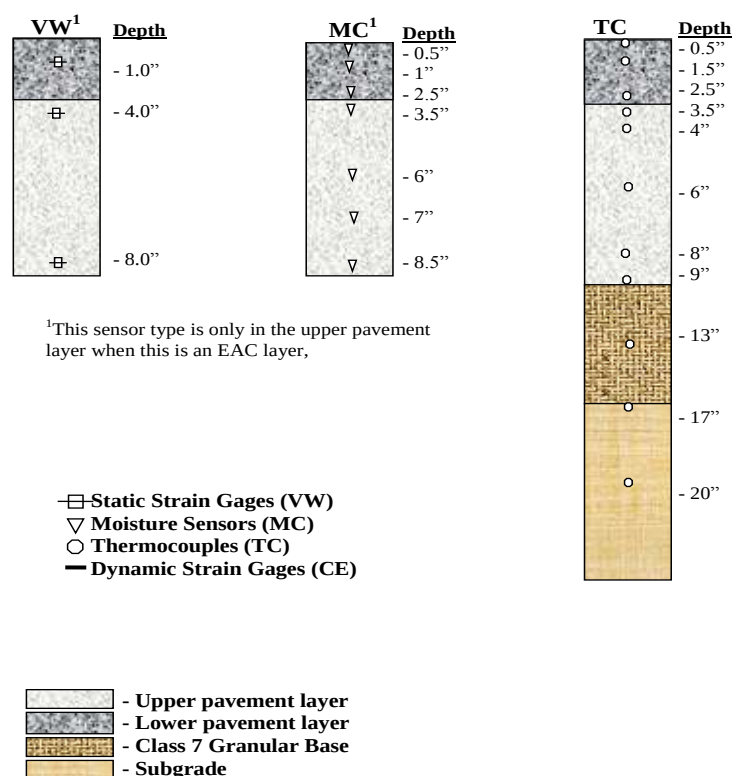


Figure 7. Technique for installing the static strain gage in the upper concrete layer for Cells 71 and 72.

The locations of these gages for each slab are presented in Figure 8. As can be seen, the sensor layout in Slab 1 is replicated in Slab 2. The distribution of the gages with depth for Cells 70, 71 and 72 can be seen in Figure 8. The climatic data is collected every 15 minutes.



a.) Sensor layout



b.) Sensor depths (1 in = 2.5 cm).

Figure 8. Sensor layout and depths for environmental sensors and static gages.

Temperature Gradients Next, the temperature and moisture data collected throughout the first year after construction will be used to quantify the effects of the difference in the magnitude of the gradients that develop in the two different composite pavement structures.

When a positive temperature gradient is present, the top of the slab is warmer than the bottom and the slab is curled downward. A negative gradient occurs when the bottom of the slab is warmer than the top and the slab is curled upward. When evaluating the expected service life of a composite pavement, it is anticipated that, if the pavement thickness is held constant, the HMA over PCC pavement would have a lower flexural rigidity when compared to a PCC over PCC pavement and hence a shorter service life. This difference in performance might be at least partly offset if

the HMA layer helps to reduce the temperature gradients that develop in the lower PCC layer as compared to the gradients that develop in the PCC over PCC pavement. The lower gradients will help in reducing the stress within the pavement and therefore increase the fatigue life. The instrumented section is used to characterize the effect of the upper HMA layer on the temperature gradients that develop in the lower PCC layer. The gradients that develop in the lower PCC layer of the HMA over PCC pavement are then compared to the gradients that develop throughout the PCC over PCC pavement.

The temperature distribution in the slab is commonly characterized as a linear temperature gradient (LTG) by normalizing the difference between the temperatures at the top and bottom of the slab by the slab thickness. Several field studies, however, have shown that the distribution of temperature throughout the slab depth is primarily nonlinear (7, 8). To account for the nonlinearity in the temperature distribution in the slab, the equivalent temperature gradient concept was developed (9, 10, 11). The equivalent linear temperature gradient (ELTG) is a gradient that would produce the same curvature in the slab as the original nonlinear temperature gradient. The ELTG concept was later generalized for non-uniform, multi-layered slabs (12, 13). The latter method in which the ELTG is established for an effective slab, with a thickness and stiffness equivalent to that of a composite multi-layer section, is employed in this study. ELTG is calculated from the temperatures at different depths, the actual temperature distribution is accounted for as a result. The ELTGs were estimated for Cells 70 and 71, using Equations 1 to 3 (11, 12).

$$\Delta T_{eff} = \frac{12}{h_{eff}^2} * \left\{ \int_{-x}^{h_{top}-x} (T(z) - T_0)zdz + \frac{\alpha_{bot} \cdot E_{bot}}{\alpha_{top} \cdot E_{top}} \int_{h_{top}-x}^{h_{top}+h_{bot}-x} (T(z) - T_0)zdz \right\} \quad (1)$$

Where, ΔT_{eff} = Difference between temperatures at the top and bottom surfaces of the effective slab;

$T(z)$ = Temperatures distribution through the PCC concrete;

T_0 = Zero-stress temperature;

z = Vertical coordinate measured downward from the neutral axis of the composite pavement;

h_{top} = Thickness of the overlay;

h_{bot} = Thickness of the overlaid layer;

α_{top} = Coefficient of thermal expansion of the overlay;

α_{bot} = Coefficient of thermal expansion of the overlaid layer;

E_{top} = Elastic modulus of the overlay;

E_{bot} = Elastic modulus of the overlaid layer;

h_{eff} = Effective thickness of the pavement, which can be determined from the following equation:

$$h_{eff} = \sqrt[3]{h_{top}^3 + \frac{E_{bot}}{E_{top}} h_{bot}^3 + 12 \left(h_{top} \left(x - \frac{h_{top}}{2} \right)^2 + \frac{E_{bot}}{E_{top}} \left(h_{top} + \frac{h_{bot}}{2} - x \right)^2 h_{bot} \right)} \quad (2)$$

x = Distance between the neutral plane and the top surface of the overlay which can be determined from the following equation:

$$x = \frac{\frac{h_{top}^2}{2} + \frac{E_{bot}}{E_{top}} h_{bot} \left(h_{top} + \frac{h_{bot}}{2} \right)}{h_{top} + \frac{E_{bot}}{E_{top}} h_{bot}} \quad (3)$$

The analysis of temperature distribution throughout the three cells constructed at MnROAD is carried out using both the LTG and ELTG concepts. By doing this, the effects of the HMA layer can be characterized with respect to the magnitude of the gradient and the degree of nonlinearity present. For all analyses, the temperature data collected at midslab is used. It should be noted that the variation between temperature distributions throughout the slab for different locations within the slab was found to not be significant and does not affect the results of the following analyses (5).

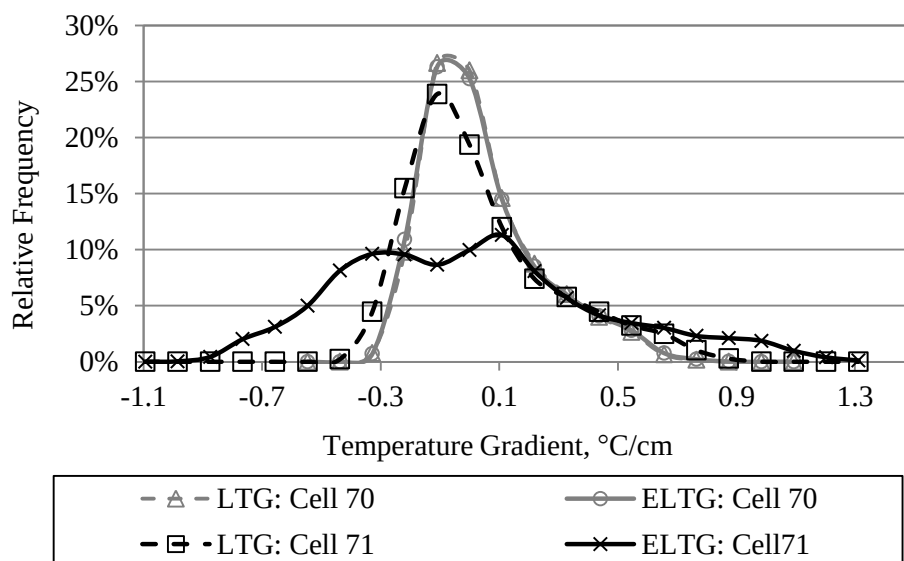
Variation in Temperature Gradient between Cells Recall that both Cells 71 and 72 are PCC-over-PCC composite pavements and Cell 70 is a HMA-over-PCC composite pavement. Unfortunately, a gap exists in the temperature data for Cell 72 for a considerable period of the first year following construction as a result of difficulties encountered with the data logger. Therefore, only the temperature data for Cell 71 will be compared with Cell 70. The analysis of the temperature distribution is carried out first based on a LTG and then using the ELTG.

Table 1 summarizes a statistical comparison made between the distributions of LTGs for these two cells. It should be noted that the temperature gradient in Cell 70 was computed only for the PCC layer because the HMA layer is not sufficiently stiff to curl. As can be seen in Table 1, the LTGs are lower for Cell 70 than Cell 71. This indicates the HMA layer does reduce the gradients that develop in the HMA over PCC pavement when compared with the PCC over PCC pavement.

Figure 9 provides a direct comparison between the average LTGs for both slabs in Cells 70 and 71. Based on this figure, Cell 70 shows a higher frequency of occurrence of gradients near zero and a lower frequency of larger gradients, when compared to Cell 71. To investigate the significance of the variation in the LTGs between the two cells, a paired t-test for two sample means is performed. Results of the t-test are summarized in Table 1. It was found that with a 95 percent level of confidence the difference between the values of LTG in Cells 70 and 71 are statistically significant.

Table 1. Comparison of statistics of LTG between Cells 70 and 71

	LTG, °C/cm			
	Cell 70		Cell 71	
	Slab 1	Slab 2	Slab 1	Slab 2
Average	-0.014	-0.017	-0.017	-0.019
Maximum	0.727	0.737	0.861	0.906
Minimum	-0.401	-0.431	-0.480	-0.494
Standard Deviation	0.192	0.197	0.241	0.255
Median	-0.060	-0.066	-0.078	-0.084
Paired T-test results				
	Cell 70		Cell 71	
Mean, °C/cm	-0.015		-0.018	
Variance, °C/cm	0.038		0.061	
Observations	28649			
Hypothesized Mean Difference	0			
Degree of Freedom	28648			
t-statistics	4.58			
p-value	0			
Critical Two-tail	1.96			

**Figure 9.** Comparison of relative frequencies for LTGs and ELTGs in Cells 70 and 71.

The LTG alone is not sufficient in characterizing the actual variation of the temperature throughout the depth. The nonlinearity of the temperature distribution should also be evaluated. Temperature distributions in the slabs throughout a single summer day for Cells 70 and 71 are plotted in Figures 10a and 10b, respectively. As can be seen, the deviation of the temperature profiles from a linear gradient is more pronounced in Cell 71. The upper HMA layer helps to buffer the lower PCC layer from more rapid temperatures swings, thereby reducing the potential for highly nonlinear temperature distributions to develop in the upper portion of the PCC layer.

The variation of temperature gradient in terms of the ELTG was evaluated so the nonlinearity of the gradient could be evaluated.

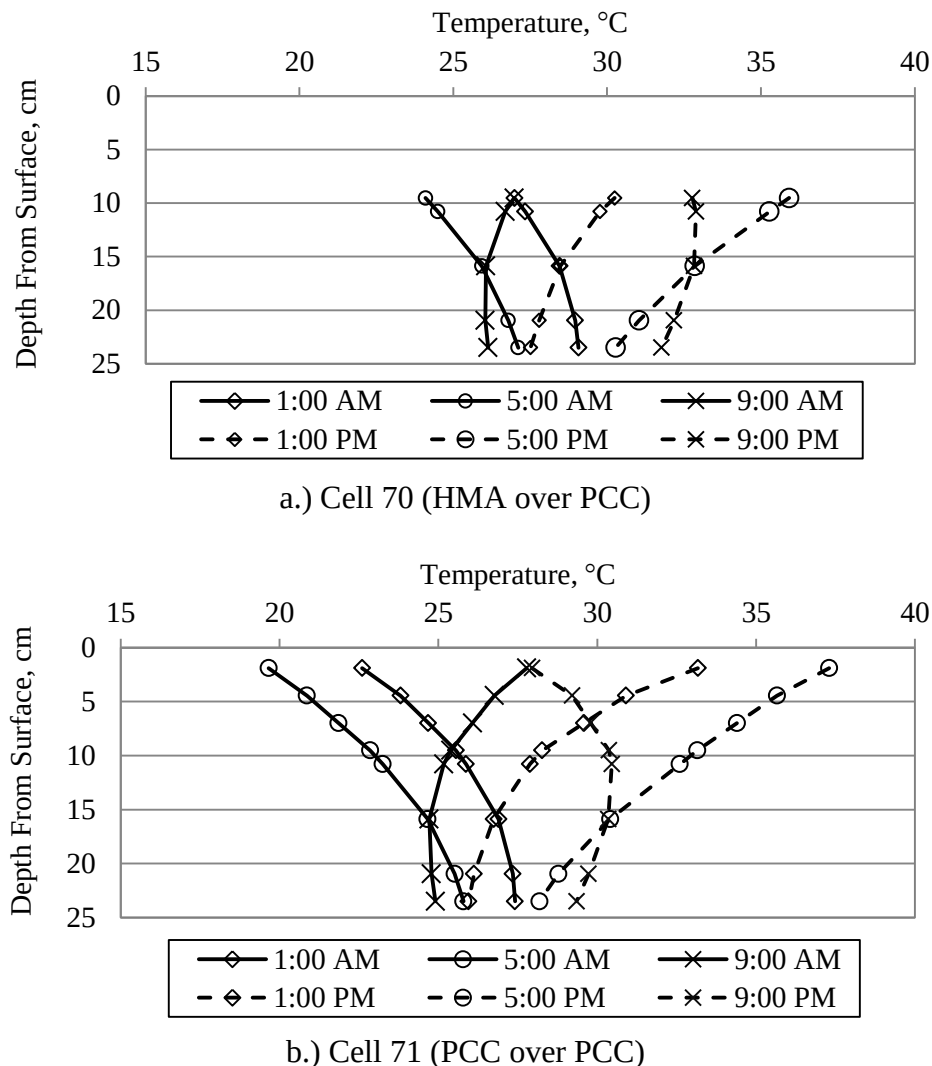


Figure 10. Temperature distribution in the composite sections.

Figure 9 also shows the variation in the ELTGs between Cells 70 and 71. The inputs used to compute the ELTGs for Cell 71 are provide in Table 2. Also, the temperature gradients calculated for Cell 70 were based on the 15.2 cm PCC layer so only the first portion of Equation 1 was used. The summary statistics for the ELTGs that developed in both cells is presented in Table 3. As was noted previously, Cell 70 shows a higher frequency of occurrence of ELTGs close to zero, when compared with Cell 71. It can be seen in Figure 9 that the shape of the frequency distribution curve of the LTGs and ELTGs for Cell 70 is quite similar whereas a considerable variation is observed in Cell 71. Unlike LTGs, ELTGs in Cell 71 are distributed over a large range. To investigate the significance of variation between the LTGs and ELTGs within a cell and the variation of each of these gradients between the cells, a paired t-test for two sample means was performed. Results of these t-tests are provided in Tables 3 and 4. The variation between the LTGs and ELTGs in Cell 70 is not significant whereas it is quite significant for Cell 71. The results of the paired t-test for the ELTGs between Cells 70 and 71 also conclude the difference in the ELTGs is significant at a 95% confidence level. The ELTG and LTG distributions for the two

composite pavement structures are comparable. The ELTG is larger than the average LTG in Cell 71.

Table 2. Inputs for computing ELTGs in Cell 71.

Input	Value
h_{top} , cm	7.6
h_{bot} , cm	15.2
E_{top} , MPa	30,350
E_{bot} , MPa	30,350
T_o , °C	12.78
α_{top} , /°C	10.8
α_{bot} , /°C	7.2

Table 3. Comparing the LTG and ELTG within each cell for Cells 70 and 71.

	Cell 70		Cell 71	
	LTG	ELTG	LTG	ELTG
Average, °C/cm	-0.015	-0.015	-0.018	-0.043
Variance, °C/cm	0.038	0.040	0.061	0.184
Observations	28649			
Hypothesized Mean Difference	0			
Degree of Freedom	28648			
t-statistics	1.43		14.64	
p-value	0.15		0	
Critical Two-tail	1.96		1.96	

Table 4. Comparing the ELTG Statistics for Cells 70 and 71

	ELTG, °C/cm	
	Cell 70	Cell 71
Average	-0.015	-0.043
Maximum	0.774	1.302
Minimum	-0.408	-1.028
Standard Deviation	0.199	0.429
Median	-0.064	-0.074
Paired t-test results		
Variance, °C/cm	0.040	0.184
Observations	28649	
Hypothesized Mean Difference	0	
Degree of Freedom	28648	
t-statistics	15.11	
p-value	0	
t Critical Two-tail	1.96	

An equivalent linear temperature gradient obtained using Equations 1 through 3 will result in approximately the same deflection profile of the slab as the actual nonlinear temperature profile. This is because a nonlinear temperature profile is the superposition of three components. These three components are the uniform temperature component, the linear temperature component and the nonlinear temperature component. The first component is responsible for the uniform expansion and contraction of the slab, while the second component results in curling of the slab. The last component, the nonlinear portion of the temperature profile, results in no temperature moment and therefore does not influence the deflection profile of the slab. This third component will result in residual stresses across the depth of the concrete, although this stress has been shown to be relatively small (14).

The shape of the profile of the slab due to the linear gradient does play a significant role in the development of stress within the pavement because a larger unsupported area increases stress due to 1. the restraint (slab self-weight, dowel and tie bars, etc.) of deformation and 2. the application of a wheel load on this unsupported area. Now that the temperature distributions have been characterized, a stress analysis should be performed to quantify the effect of these temperatures gradients on the service life of these composite pavement structures.

Moisture Gradients Besides temperature variation within the slab, the moisture variation throughout the depth with time is also an important aspect in the design of composite pavements. It has been reported in previous research that the moisture content in the upper 5 cm of the slab fluctuates while the moisture content at the bottom of the slab remains saturated (15). This is attributed to the low porosity of the concrete limiting the diffusion of moisture through the concrete and into the environment. This moisture gradient creates an upward warping of the slab, which effects the stress development. The magnitude of this warping stress varies with the season.

To capture the variation in the moisture content across the depth of the concrete layers during different seasons, the relative humidity of the concrete was measured at different depths and locations in all of the cells. It should be noted the moisture content in the concrete cannot be measured directly and must be estimated based on the measured relative humidity. Therefore, when interpreting this data, it is important to remember that the relative humidity will increase when the temperature decreases even when the moisture content remains constant.

To evaluate the effect of the placement of the HMA layer on top of the PCC layer Figure 11 was generated. This depicts the relative humidity and temperature at the top and bottom of the PCC layer for a three day period at the time when the HMA layer was placed (May 20, 2010), which was approximately two weeks after the lower PCC layer was paved. Placement of the HMA overlay in Cell 70 resulted in an observable decrease in relative humidity, especially near the surface of the lower PCC layer (12.2 cm (4.8in) from the HMA surface) as is seen in Figure 13. The high temperature of the HMA when placed increased the rate of evaporation of moisture in the slab. The moisture content of the PCC layer under the HMA was then seen to increase with time. This rewetting process was not observed in the PCC over PCC pavements.

A better interpretation of the change in the moisture content in the concrete will be possible after several years of data has been collected so that comparisons within season can be made. By making these comparisons within the same season of

subsequent years, the effects of temperature on the relative humidity measurements can be better isolated.

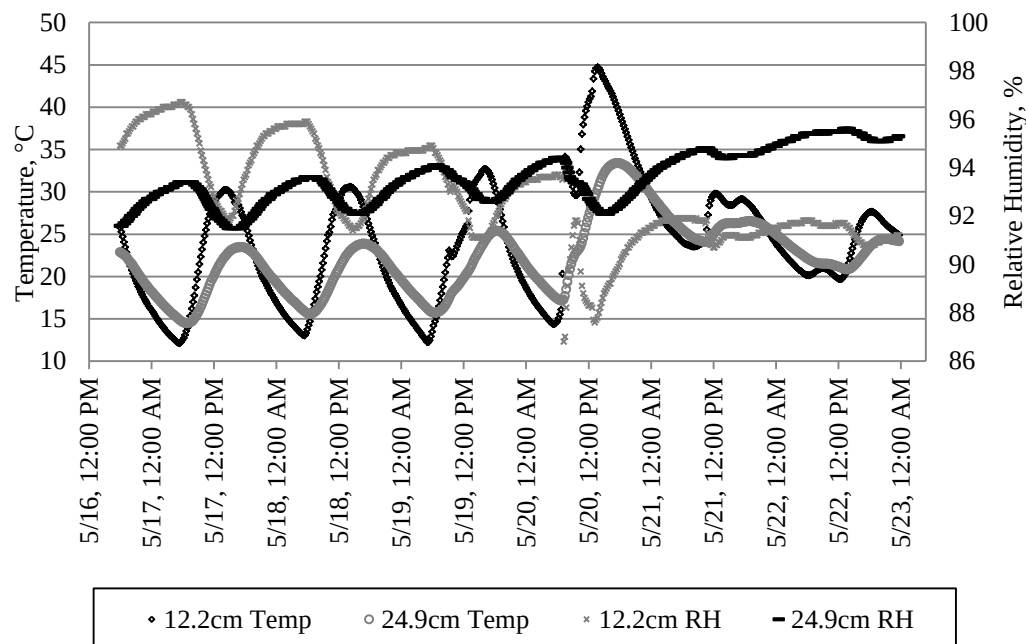


Figure 13. Daily variation in relative humidity and temperature in the RC, four days before and three days after the HMA overlay was placed in Cell 70.

Conclusions

A novel approach for the instrumentation of composite pavements was presented. This instrumentation was used to quantify and compare the magnitude of the gradients that develop in HMA over HMA and PCC over PCC composite pavements. Based on the t-test it was found that there was a significant difference in the trends of the LTG and ELTG between Cell 70 and Cell 71. Cell 70 experiences a higher frequency of occurrence of zero and close-to-zero LTGs and ELTGs when compared to Cell 71. This finding suggests that the HMA overlay reduces the nonlinearity of the temperature gradient in HMA over PCC composite pavements. Now that the magnitude of the gradients that develop in these structures throughout the year has been established, a stress analysis should be performed to quantify these effects on the service life of the structures.

The effects of the construction of the HMA layer over the lower PCC layer on the moisture content in the concrete were also investigated. It was shown that the placement of the HMA overlay temporarily decreased the moisture content in the upper portion of the concrete layer.

Acknowledgments

The authors would like to gratefully acknowledge the Strategic Highway Research Program 2 for funding this research effort. The authors would also like to thank Drs. Michael Darter, Shreenath Rao with ARA, Inc. and Dr. Lev Khazanovich with the University of Minnesota for his contribution to the field work. They would also like to thank Mr. Jack Herndon, Robert Strommen and Leonard Palek who helped in the development of these innovative installation techniques as well as the many others at

the Minnesota Road Research Facility for their effort in the construction and instrumentation of these pavement sections.

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