# Temperature and Velocity Effects on a Flexible Perpetual Pavement

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# ABSTRACT

Perpetual pavements have become a viable design option for flexible pavement designers. These pavements are designed with appropriate materials and thickness such that critical pavement responses (e.g., stress, strain) are kept below certain thresholds resulting in surface distresses that are easily remedied. The success of a perpetual pavement hinges on accurately predicting these pavement responses. For perpetual pavements to gain wider acceptance, there is a need to develop a deeper understanding of how these pavements will perform under a variety of conditions. To meet this need, a perpetual pavement was constructed at the National Center for Asphalt Technology (NCAT) Pavement Test Track, a full-scale accelerated loading facility for flexible pavements located in Alabama. This test section consisted of 14 inches of HMA and was instrumented with an array of strain gauges to measure horizontal strain at the bottom of the HMA. Temperature probes were used to capture the full temperature profile of the structure. In the context of perpetual pavements, the effects of pavement temperature and vehicle speed on measured tensile strain were examined. Four testing cycles were conducted in the spring of 2007 consisting of gathering dynamic strains for test speeds ranging from 15 mph to 45 mph in increments of 10 mph. The results showed a general decrease in strain with increasing speed, whereas a general increase in strain resulted from increasing temperatures. The effect of both factors, which is an important consideration for both perpetual and traditional flexible pavement design, was characterized for the measured response data.

# INTRODUCTION

## Background

Mechanistic-empirical (M-E) design procedures such as the Mechanistic Empirical Pavement Design Guide (MEPDG) utilize material characteristics, climate, and layer thickness to predict pavement responses under loading (*1, 2)*. Transfer functions are then employed to predict pavement performance based on the computed responses. Responses that are essential to the successful prediction of load repetitions to failure include the horizontal tensile strain at the bottom of the Hot Mix Asphalt (HMA) layer to predict fatigue cracking, and the vertical compressive strain at the top of the subgrade layer to predict rutting.

The horizontal tensile strain is of particular interest for the design of perpetual pavements which have come to the forefront of the asphalt industry in recent years. One key feature of these long lasting pavements is that each layer is designed to resist specific distresses. In particular, the bottom layer is designed to resist bottom-up fatigue cracking by considering the flexibility and thickness of the HMA (*3*). Fatigue cracking is dependent on the horizontal tensile strain induced at the bottom of the HMA. If these strains are kept below a maximum value it is believed that the pavement can sustain an infinite number of load repetitions without failing by fatigue (*4*). As a result of the zero damage incurred, the number of load repetitions that occur at or below the strain threshold can be ignored in determining the load repetitions to fatigue failure, ultimately reducing the required layer thickness. Therefore, properly predicting the tensile strains at the bottom of the HMA is critical to designing a successful and cost-efficient perpetual pavement.

Early estimates of the threshold were approximately 70 με while more recent observations have reported a threshold of 100 με (*4, 5*). These thresholds, however, are largely based upon laboratory fatigue testing and require field validation for use in the structural design of perpetual pavements. It has been well established that there are large shift factors needed when translating results from laboratory fatigue testing to field performance and some researchers argue that there is no accurate way to translate laboratory results to actual performance (*6*). It is likely that there also exists a factor when considering the fatigue threshold and therefore field evaluation is warranted.

Pavement responses, specifically tensile strain, can be difficult to characterize due to the viscoelastic nature of HMA. Because of its viscous properties, HMA is time-dependent, such that as a load is applied, a response is not immediately induced throughout the pavement. Additionally, it is dependent on temperature, causing increased flexibility under warmer temperatures and increased stiffness under colder temperatures. The prediction model becomes increasingly complex when the pavement is under dynamic loading, such as the loading that occurs with live traffic.

Researchers and engineers have characterized these time-temperature relationships both theoretically and through physical measurement. Although developing a temperature-strain relationship was not the primary area of investigation in Mateos and Snyder's validation of a response model from the Minnesota Road Research test facility (Mn/ROAD), a trend of increasing strain with increasing pavement temperatures was illustrated in their findings (*7*). Observations from the National Center for Asphalt Technology (NCAT) Test Track have reported that an increase in temperature has resulted in an increase in horizontal tensile strain. This relationship was found to be well-modeled by a power function of the mid-depth pavement temperature (*5*).

Investigations at the PACCAR Technical Center into the effects of vehicle speed on strain have revealed a reduction in tensile strain with increasing speed (*8*). For tensile strain in the longitudinal direction at the bottom of the HMA layer, a maximum reduction of 30-40% was reported as vehicle speeds were increased from creeping motion to 64 km/h (*8*). Similarly, transverse strain at the bottom of the HMA layer was also reported to decrease with speed, although not as significantly (*8*). Mateos and Snyder (*7*) also recorded a decrease in tensile strains in both the transverse and longitudinal direction with changes in vehicle speed.

Recent research efforts at the NCAT Test Track have included investigations of perpetual pavements. The Oklahoma Department of Transportation (ODOT) has sponsored perpetual pavement sections at the Test Track to examine their behavior in an accelerated loading environment. One of the long-term goals of this research is to characterize the performance of their perpetual sections so that the relevant mix design and structural design procedures can be refined prior to widespread implementation throughout Oklahoma. Central to this effort is characterizing a field-based threshold for structural design. To accomplish this goal, both pavement response and performance require characterization. As described below, this paper focuses primarily on pavement response characterization.

### Objectives

Given the needs regarding perpetual pavement design thresholds stipulated above, the objectives of this study were:

1. Characterize the effects of temperature and speed on measured perpetual pavement response.
2. Describe the strain history of the perpetual pavement in the context of existing response thresholds.

### Scope

To meet the objectives, a pavement section of the 2006 NCAT Test Track was selected for investigation. The section, N9, consisted of approximately 14 inches of HMA. The deep cross-section allowed for instrumentation at various depths, enabling the collection of detailed information regarding temperature and strain. For this investigation, live traffic was applied at various speeds over the course of a one month testing cycle in the spring of 2007. Regression equations were developed to express strain as a function of speed and temperature. The equations were then used to provide a strain history of N9 at the Test Track.

## FIELD TESTING

### Test Section

Generally speaking, testing conducted on the NCAT Test Track's structural sections consisted of live loads applied over instrumented test sections to measure responses within the pavement. The live loads were applied through the use of heavy trucks that were driven around the 1.7 mile track at a constant speed. This experiment consisted of the application of live loads at a minimum of 4 different speeds on 4 different dates to measure the strain induced throughout the N9 test section. During the testing, temperatures throughout the pavement structure were also monitored. Section N9 was a perpetual pavement section that spanned 200 feet and was comprised of approximately 14 inches of various asphalt concrete layers over a 9.6 inch granular base. From top to bottom, the layers of the pavement structure are shown in Figure 1.

*Instrumentation*

Section N9 was instrumented with pressure plates, asphalt strain gauges and temperature probes to capture the pavement's response under the various loading conditions and temperatures. Two pressure plates were installed during construction of the pavement section, one at the top of the base layer, and the other at the top of the subgrade layer to record the vertical compressive stresses at these locations. A total of 24 strain gauges were installed within the structure. However, for this investigation, only the strains captured by the bottom 12 gauges were relevant. These 12 gauges were oriented in an array, as shown in the inset of Figure 1, at the bottom of the rich bottom layer, 13.92 inches deep. The longitudinal gauges were oriented to detect the strain that occurred in the direction of travel. Conversely, the transverse gauges were oriented to detect the strain induced perpendicular to traffic. They were oriented such that within each group of three, one was placed along the center of the outside wheel path (OWP), one was offset to the right and the other was offset to the left. This helps reduce the effect of wheel wander, improving the chance of capturing the maximum strain (i.e., direct hit) regardless of the load's deviation from the center of the wheel path. Two of each gauge were installed for redundancy in the event that one gauge became disabled. Additionally, redundant gauges increased the chance that the maximum strain induced in the pavement would be captured.

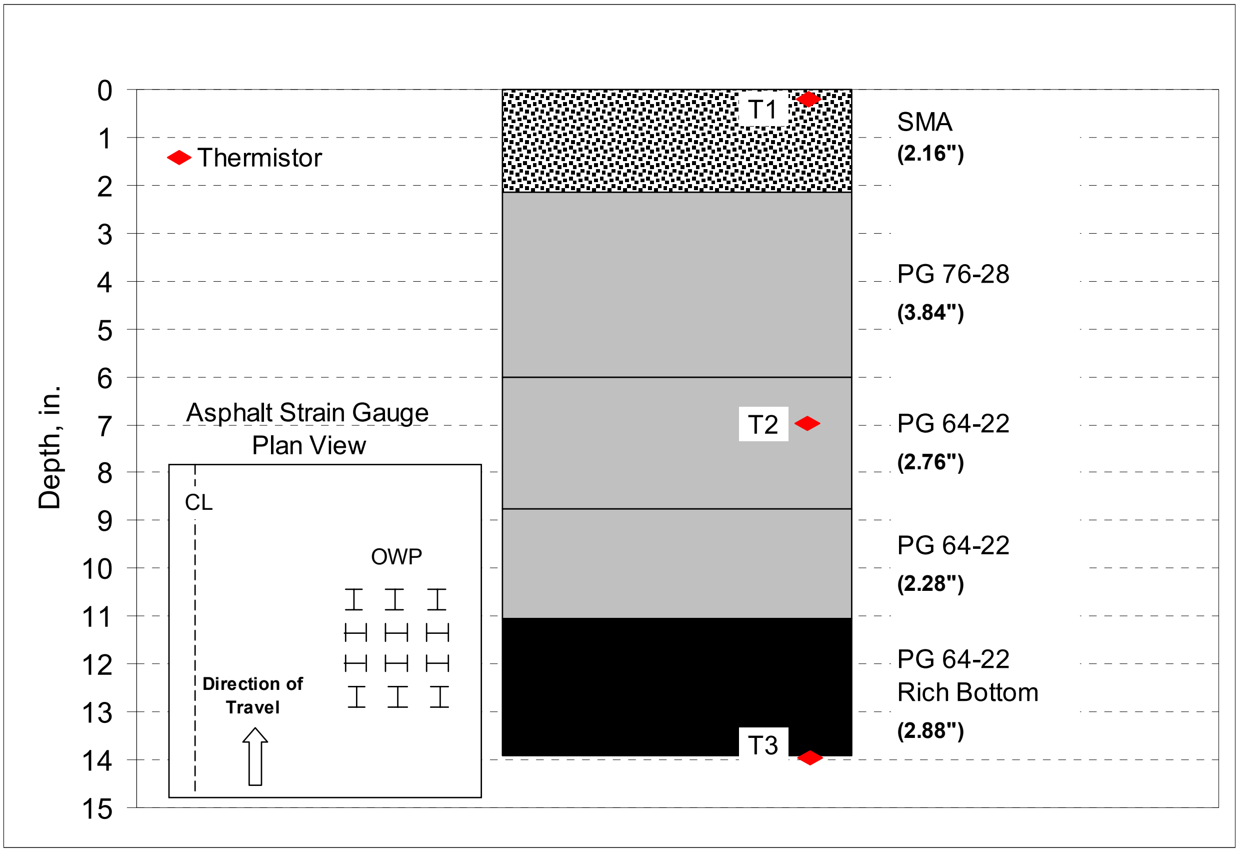

**FIGURE 1 Pavement Cross-Section, Exposing Location of Gauges.**

Additionally, temperature probes were installed within the structure. In Figure 1, the probes (labeled Thermistor, T1 through T3) were installed at the surface, mid-depth (7.0 inches deep), and bottom of the asphalt pavement structure (14 inches deep). A fourth thermistor was also installed at the same location, embedded in the base layer at approximately 17 inches deep. These gauges proved valuable in relating temperature to strain measurements.

### Applied Loads

The loads were applied using heavy trucks, each consisting of a 12-kip steer axle, a tandem axle, with each of the paired axles weighing 20 kips (for a combined axle weight of 40 kips), and five trailing 20-kip single axles. For this experiment, the tandem axle was considered one axle group, making the total number of axle groups on each truck seven. Although these axle weights do not represent entire load spectra to be found on open access facilities, they do serve as conservative design loads for perpetual pavement analysis. For example, in version 1.0 of the MEPDG, a 20-kip single axle falls between the 92nd and 99th percentile (depending on vehicle type) for the default load spectra. Furthermore, in the default load spectra, a 40-kip tandem axle falls in the percentile range of the 92nd to 98th percentile, again depending on vehicle type. It should also be noted that at each speed tested, a minimum of four trucks were run, passing over the test section three times each. This was done to ensure a "best hit" was measured by the instrumentation.

### Testing Dates and Speeds

Testing was conducted on April 6, 10, 25 and May 2, 2007. On each date the trucks traveled at four speeds: 15 mph, 25 mph, 35 mph, and 45 mph. On the first two dates, data were also gathered at 55 mph. However, for safety reasons, it was decided to discontinue testing at this speed on the remaining dates (the Test Track is designed for 45 mph). For each speed tested, the trucks adjusted to the test speed prior to traveling over the test section, such that once over the test section, the traveled speed was constant. It should be noted that section N9 was subjected to "routine" traffic at 45 mph as part of the overall Test Track trucking operation. Five trucks were applied 16 hours per day, 5 days per week. The various test speeds used in this particular investigation were intended to provide a wider range of conditions and therefore more applicability to potential lower-speed conditions off the Test Track.

## FIELD RESULTS AND DISCUSSION

The results of the tests were processed and transformed into useable data to analyze the pavement's response due to the speed at which the load was applied and the in-situ temperature of the pavement. The useable data was in the form of strain traces, which plotted the strain ($\mu\varepsilon$) against time. These strain traces allowed for the definition of the induced strain under dynamic loading and for the analysis of strain due to vehicle speed and pavement temperature.

### Strain Definition

As a tire load is applied to a flexible pavement, the material bends to absorb and distribute the load. As the material bends, the bottom of the HMA is in tension, whereas at the top of the HMA, the material is in compression. While theoretically, strain is occurring in all directions, they are measured in two principal directions; longitudinal (direction of travel) and transverse (perpendicular to travel). When a dynamic or moving load is applied, depending on the location of the load relative to a point in the pavement, the material can experience tension, compression or both. In this test, heavy trucks comprised of 7 axle groups each were used to apply the dynamic load and strain responses were measured in the longitudinal and transverse directions.

An example of the strain induced in the longitudinal direction by a single axle is shown in Figure 2. The plot illustrates that in the longitudinal direction both compressive (negative values) and tensile strain (positive values) were induced at the bottom of the HMA. In the transverse direction, traces revealed a loading pattern similar to the ones illustrated in Figure 2, with one exception, strain occurred in tension only. Additionally, the trace shows distinct differences in the amount of time that the pavement was loaded at various speeds. The loading due to any axle begins as the strain level deviates from the baseline strain (strain of zero) as an axle group comes in proximity of the strain gauge. At the moment the axle group is as close to directly over the gauge as possible, the maximum strain (for that individual trace) is induced in tension, described by the peak of the traces in Figure 2. The loading concluded as the strain level returned to or closely to the baseline strain level. The load duration was taken to be the difference in time from the beginning to end of loading. As was expected, the load duration was found to be greater at slower speeds.

In investigating the effects of speed and temperature on strain within the pavement, focus was placed on the tensile strain induced at the bottom of the HMA, where the maximum strain throughout the pavement occurs. The tensile strains captured for all three passes of the trucks at a particular speed and date were compiled separately by direction and axle type. Among the strains captured from the six longitudinal (and six transverse) gauges the maximum of the strains induced under each axle type was selected for the date and speed in question, resulting in one longitudinal tensile strain and one transverse tensile strain for each date, speed, and axle type. Selecting the maximum strain gave the best hit on the gauge array, such that the strain selected was that induced by the axle group pass that came closest to traveling directly over the strain gauge. It was imperative that the strains compiled included all six gauges in each direction as wheel wander was a factor.

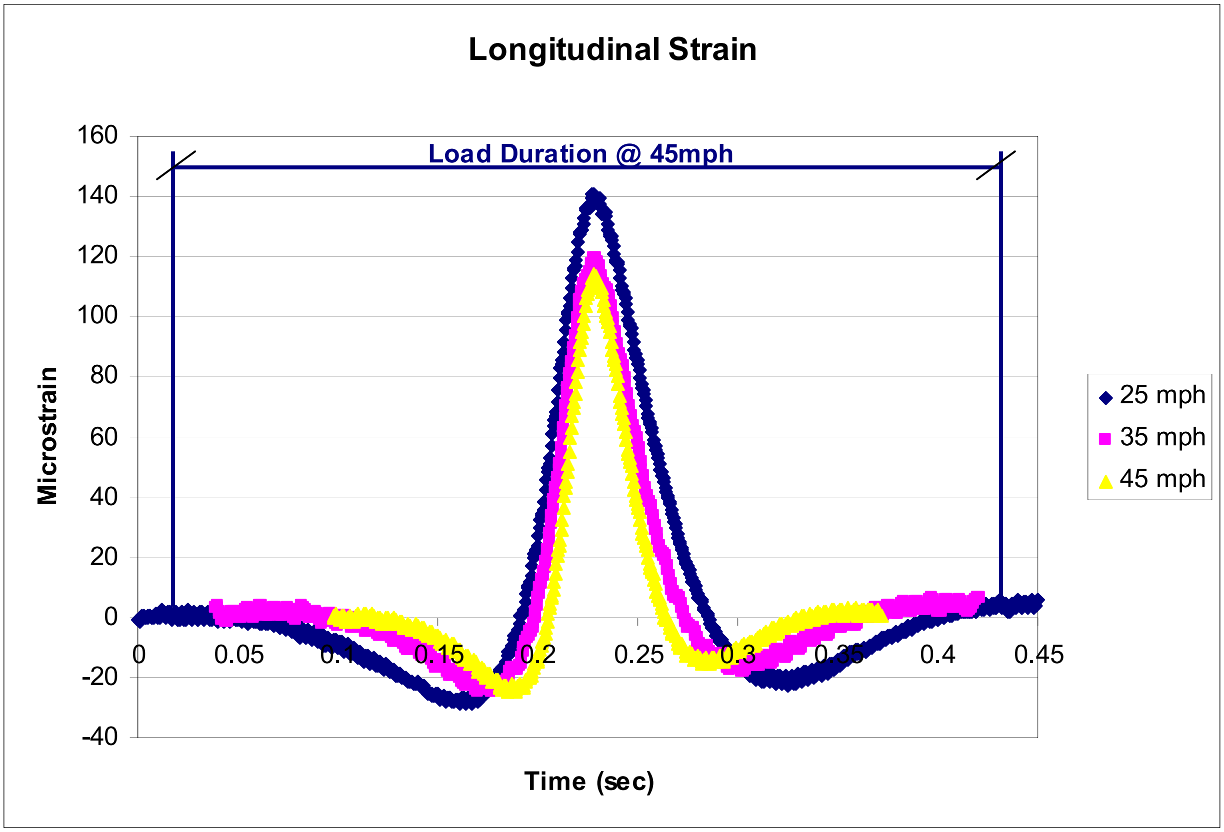

**FIGURE 2 Sample Strain Trace for a Single Axle.**

**Strain vs. Speed**
The strains determined from the best hit selections were investigated to determine the effects on tensile strain at the bottom of the HMA layer of a perpetual pavement. These values were plotted in Figure 3 to investigate the relationship between vehicle speed and tensile strain. For the first two dates, April 6, and April 10, 2007 the induced longitudinal strain decreases with an increase in speed. The same trend exists for the last two dates; however, the strain decreased at a greater rate than on the first two dates for each increase in speed. This trend is more evident by plotting in Figure 4 the rate of strain change due to vehicle speed (slopes of the trend lines in Figure 3) versus mid-depth pavement temperature. At high mid-depth temperatures vehicle speed reduced the longitudinal strain at a greater rate, whereas at colder mid-depth temperatures, the rate of reduction nears zero. Therefore, at warmer temperatures vehicle speed is more influential in reducing the tensile strain at the bottom of the HMA than at colder temperatures. This was to be expected since warmer temperatures induce a greater viscoelastic behavior from the HMA thus increasing the impact of vehicle speed.

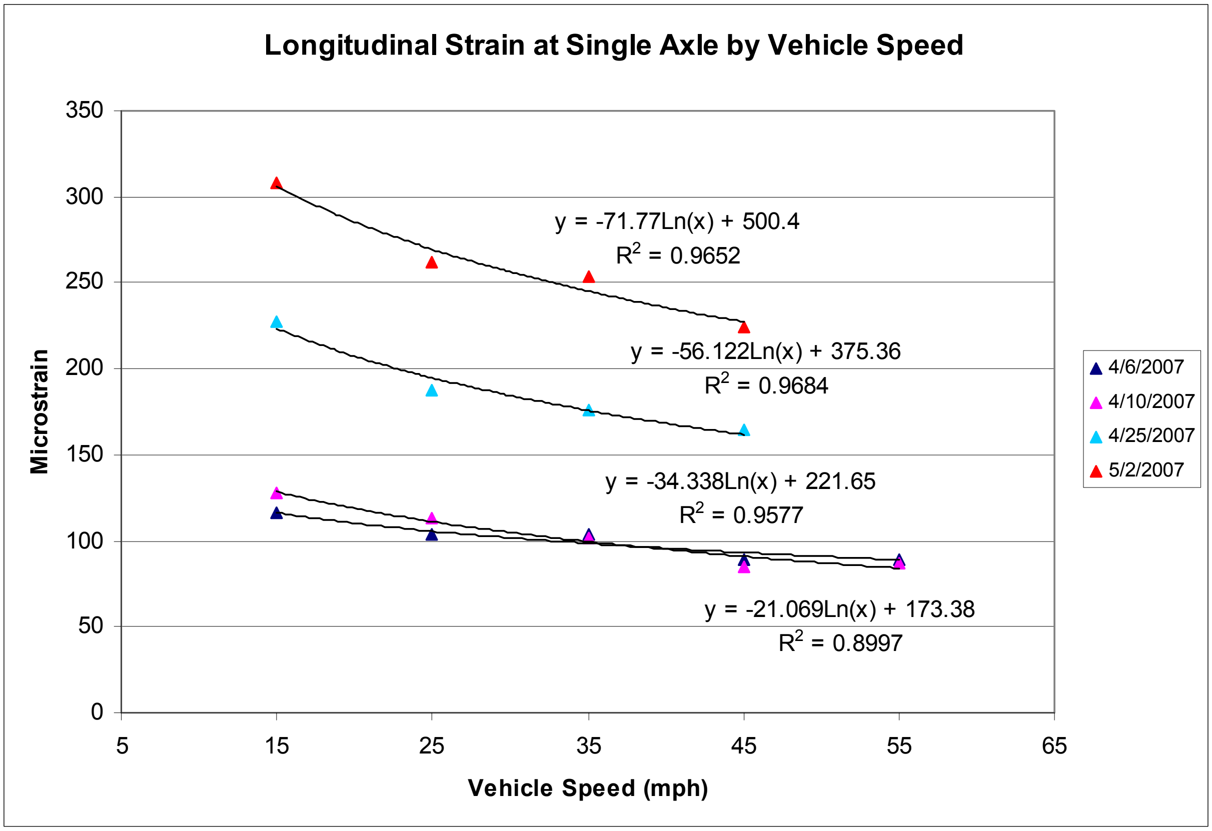

**FIGURE 3 Speed-Strain Relationship for a Single Axle.**

For all test dates and axle types the same general trend exists: increasing the vehicle speed resulted in a decrease in the amount of strain that was induced. By using Excel to attach a trend line to the data, it became evident that the longitudinal strain was proportional to the natural logarithm of the speed of the applied load, modeled by Equation 1. The goodness of fit, corresponding to the trend line for each axle type on each test date revealed that Equation 1 models the relationship very well, returning $R^2$ values ranging from 0.7999 to 0.9983 with the majority of the $R^2$ values greater than 0.90. The same trends existed for strains under each axle type in the transverse direction. Equation 1 can also be used to describe those strains, returning relatively high $R^2$ values.

$$y = a \ln x + b \tag{1}$$

where:

y = tensile strain (microstrain)
x = speed of applied load (mph)
a, b = regression coefficients (see Figures 5-7)

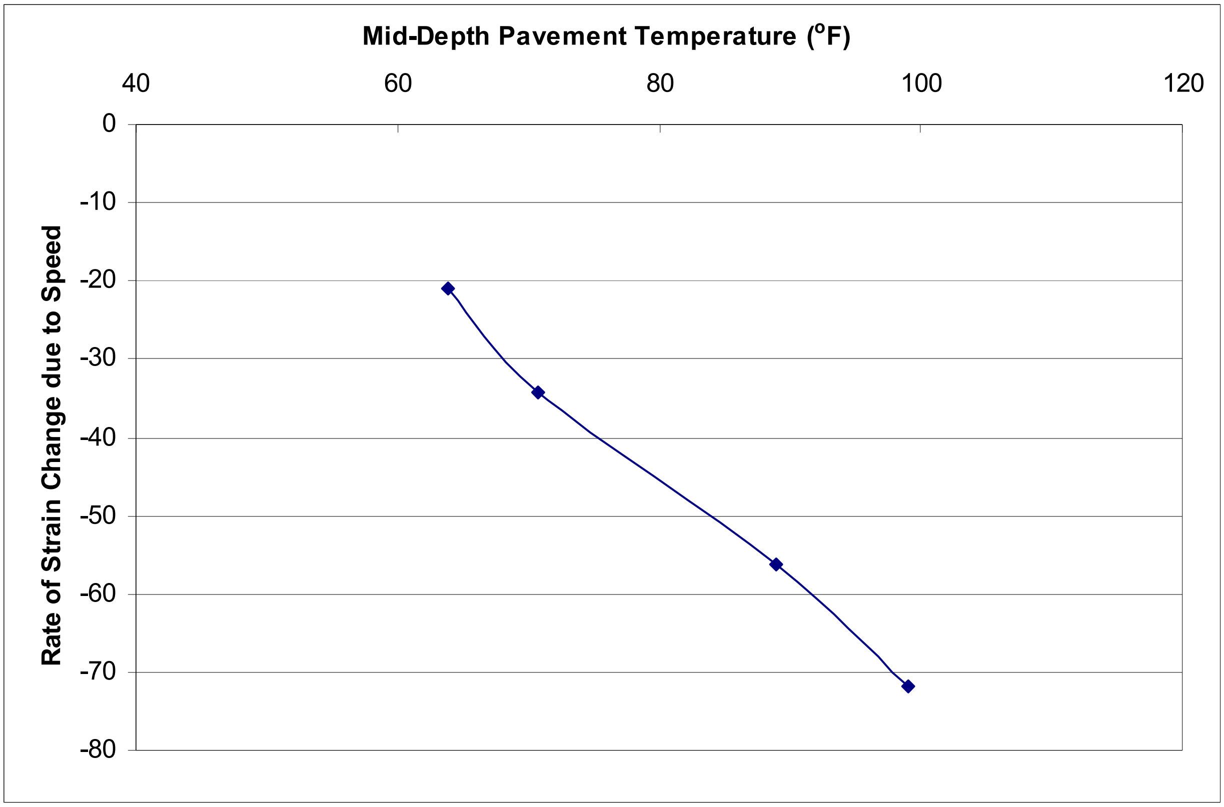

**FIGURE 4 Rate of Strain Change by Mid-Depth Temperature.**

## Strain vs. Temperature

By conducting the experiment on four different dates throughout the month of April and beginning of May, a wide range of in-situ pavement temperatures were experienced. Pavement surface temperatures (in degrees Fahrenheit, °F) ranged from the low 70s to low 120s. Temperatures from all probes were recorded prior to the start of each test. As to be expected, the temperature throughout the structure rose as the experiment progressed throughout the month of April and into the month of May. Additionally, surface temperatures were significantly higher than temperatures at the bottom of the asphalt concrete.

To determine which temperature probe was the best predictor of strain, the strain (both longitudinal and transverse) induced under the steer axle at the bottom of the asphalt concrete due to speed was plotted against the temperatures recorded by each temperature probe. Probes T1 through T4 were selected for analysis as these four cover the entire spectrum of temperatures recorded across the pavement profile. For each direction and speed tested, a regression equation and its associated $R^2$ value (representing the goodness of fit) were generated, allowing a comparison of accuracy among all four probes. To determine which temperature probe to use, the $R^2$ values for each probe were compared. From this, it was determined that the temperatures recorded at mid-depth by probe T2, returned trend lines with $R^2$ values that were very high and that were the most consistent across all speeds tested. Therefore, mid-depth temperatures were chosen for the analysis of the strain-temperature relationship under each axle type and speed tested. A previous investigation at the Test Track also selected mid-depth temperature as the best predictor of strain (*5*).

To further investigate the effect of temperature on strain, the maximum tensile strain was plotted against the mid-depth temperature. The plot in Figure 6 displays the temperature-strain relationships for strain in the longitudinal direction under a single axle. This plot illustrates that an increases in mid-depth pavement temperature results in a very large increase in tensile strain, a relationship that can be described by an exponential function, of the form listed in Equation 2. The regression equation and goodness of fit ($R^2$ value), generated by Excel for the strain due to temperature at a vehicle speed of 15 mph is displayed in Figure 5. Although only the $R^2$ value for a vehicle speed of 15 mph is shown, the $R^2$ values for all four speeds were consistently very high, ranging from 0.961-0.985. These high $R^2$ values indicate that Equation 2 describes the temperature-strain relationship very well. Furthermore, the speed-strain relationship was reiterated in Figure 5, such that the highest strain values were induced at the slowest test speeds. Thus, the largest longitudinal strain occurred under a single axle traveling at a speed of 15 mph, at the highest mid-depth pavement temperature, 99.47 °F. These findings were also evident in the other two axle types: steer and tandem axles, however, the single axle consistently produced higher strain levels under loading. Similar trends were also found for the tensile strain induced in the transverse direction. The relationship described by Equation 2 was used to characterize the strain under any of the three axle types and the strain in either direction (longitudinal or transverse).

$$y = ae^{bx} \tag{2}$$

where:

y = Tensile strain (micro strain)
x = Mid-depth Temperature (°F)
e = constant, with approximate value = 2.71828183
a, b = regression coefficients

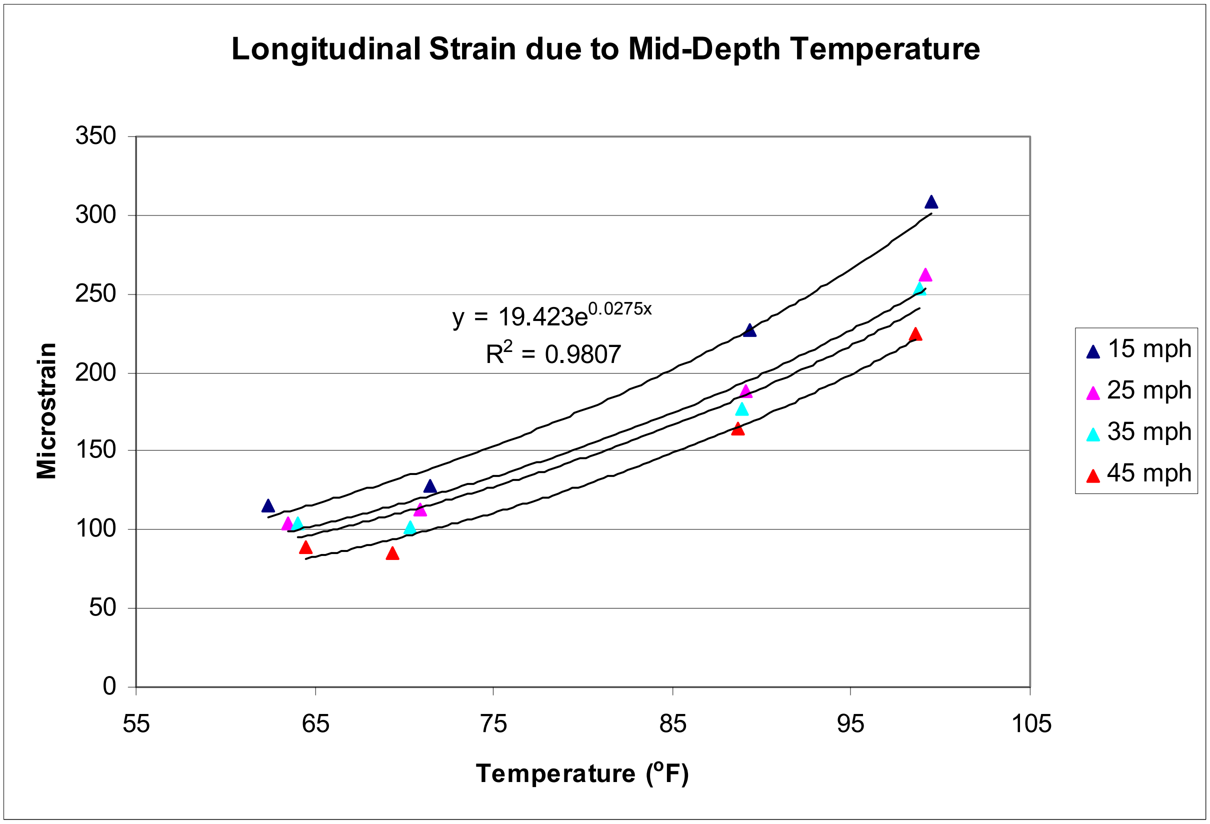

**FIGURE 5 Strain-Temperature Relationship for a Single Axle.**

## Combined Effect

It is of some benefit to know the effect of speed and temperature combined, as independently these variables greatly influence the amount of tensile strain induced in a pavement. The investigations into the effects of speed and temperature revealed that tensile strain is directly proportional to the natural logarithm of the vehicle speed and directly proportional to the exponential function of temperature. To determine the combined effect, DataFit, a regression analysis software program, was utilized to generate regression equations from the recorded data. DataFit allows the user to enter forms of regression equations not built into EXCEL. The program then iterates through possible coefficients and checks the validity of the user defined equation by calculating the correlation to the provided data. Four equations were defined for each axle type in the longitudinal and transverse direction based on the previous investigations into the independent effects of speed and temperature:

A. $y = a\ln x_1 + be^{cx_2} + d$

B. $y = a\ln x_1 + e^{cx_2} + d$

C. $y = a\ln x_1 + e^{cx_2}$

D. $y = a\ln x_1 + be^{cx_2}$

where:
y = tensile strain (micro strain)
$x_1$ = speed (mph)
$x_2$ = mid-depth pavement temperature (°F)
e = constant, with approximate value = 2.71828183

a, b, c, d = regression coefficients

Each of the above four equations were evaluated to determine the goodness of fit and the significance of each regression coefficient. DataFit revealed that although equation A above typically returned the highest $R^2$ values the "b" coefficient held little significance (based on the associated p-value). By removing the "b" coefficient, equation B above resulted with a $R^2$ value nearly equal to that of equation A. However, by removing the "d" term in equations C and D, the $R^2$ values dropped significantly. It became evident that "a", "c", and "d" terms were of most importance in describing the induced strain due to speed and temperature. Equation B utilized only these three coefficients and consistently returned very high goodness of fit values, as shown below in Figure 6. Therefore, equation B best describes the induced tensile strain due to the rate of loading and mid-depth pavement temperature. The regression coefficients for each axle type are listed in Table 1.

**TABLE 1 Regression Coefficients by Axle Type and Direction of Strain**

| | | Regression Coefficients | | | |
|---|---|---|---|---|---|
| Gauge Orientation | Axle Type | *a* | *c* | *d* | $R^2$ |
| Longitudinal | Steer | -24.25 | 0.047 | 108.81 | 0.955 |
| Longitudinal | Tandem | -34.67 | 0.051 | 172.93 | 0.970 |
| Longitudinal | Single | -40.57 | 0.053 | 206.67 | 0.983 |
| Transverse | Steer | -19.70 | 0.050 | 101.40 | 0.986 |
| Transverse | Tandem | -15.05 | 0.500 | 112.57 | 0.971 |
| Transverse | Single | -16.23 | 0.051 | 102.18 | 0.986 |

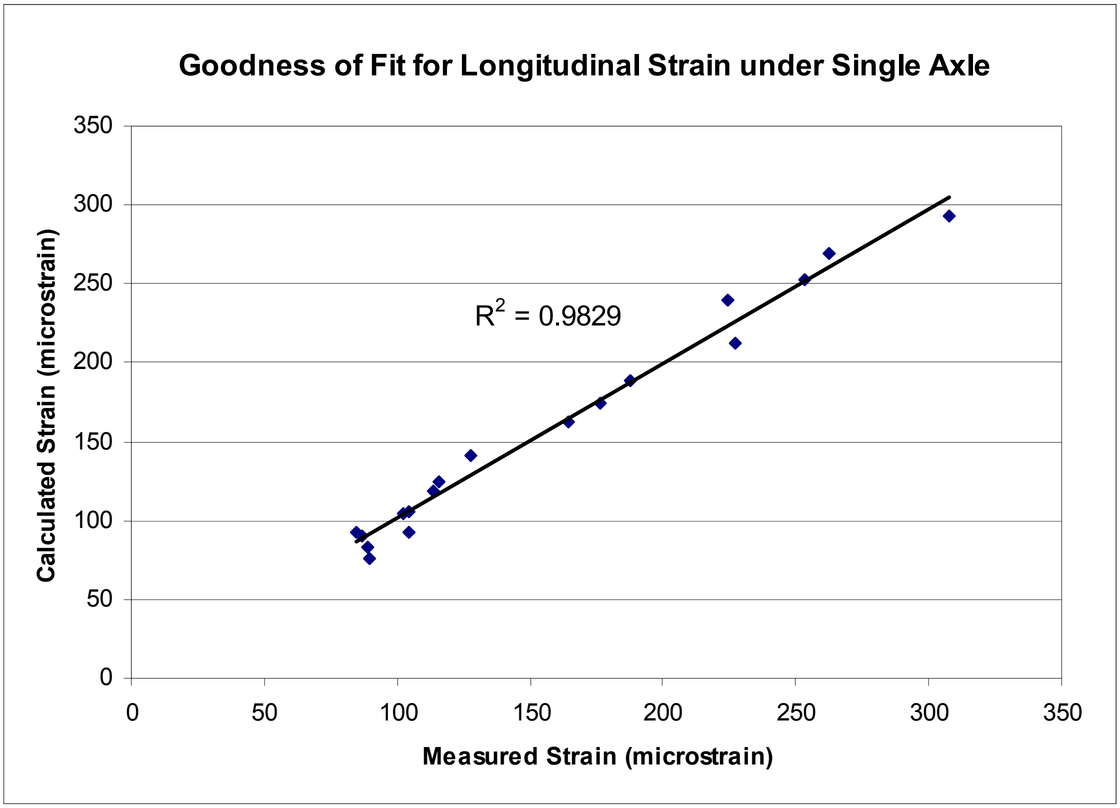

**FIGURE 6 Equation B Goodness of Fit for Longitudinal Strain at a Single Axle.**

### *Application of Regression Models*

The regression models previously developed serve two functions. The first is to characterize the effects of vehicle speed and mid-depth temperature for the pavement section investigated. The second is to provide a way to predict the tensile strains under a variety of conditions. Both are beneficial for perpetual pavement design in that the regression models can be used to determine the conditions that induce strains beyond the laboratory-established threshold limit. Further analysis stemming from these developed equations can also be utilized to assess the relevance of laboratory-established thresholds to field conditions.

To determine the most critical conditions for the perpetual pavement investigated, five speeds (15, 25, 35, 45, and 65 mph) and five mid-depth pavement temperatures (40, 60, 80, 100 and 120°F) were selected to predict tensile strains from the aforementioned regression equations. The vehicle speeds were representative of those included in the experiment, with the addition of one speed (65 mph) outside the range that was selected to reflect highway speeds. For the mid-depth pavement temperatures chosen for this analysis, three temperatures were experienced in the experiment and the two additional temperatures (40 and 120°F) allowed for extrapolation of strains to temperatures experienced at the Test Track but not specifically part of this experiment.

The longitudinal tensile strains predicted for a single axle were plotted in Figure 7, as well as a threshold level of 100 με. As expected, a vehicle speed of 15 mph is most critical for the N9 test section, inducing strains above the threshold for all of the selected temperatures. The critical mid-depth pavement temperature was found to be approximately 78°F for vehicle speeds of 65 mph or less. At these conditions the predicted strains were equal to the threshold value of 100 με; therefore, at lower mid-depth temperatures, zero damage would theoretically be incurred under an infinite number of load applications.

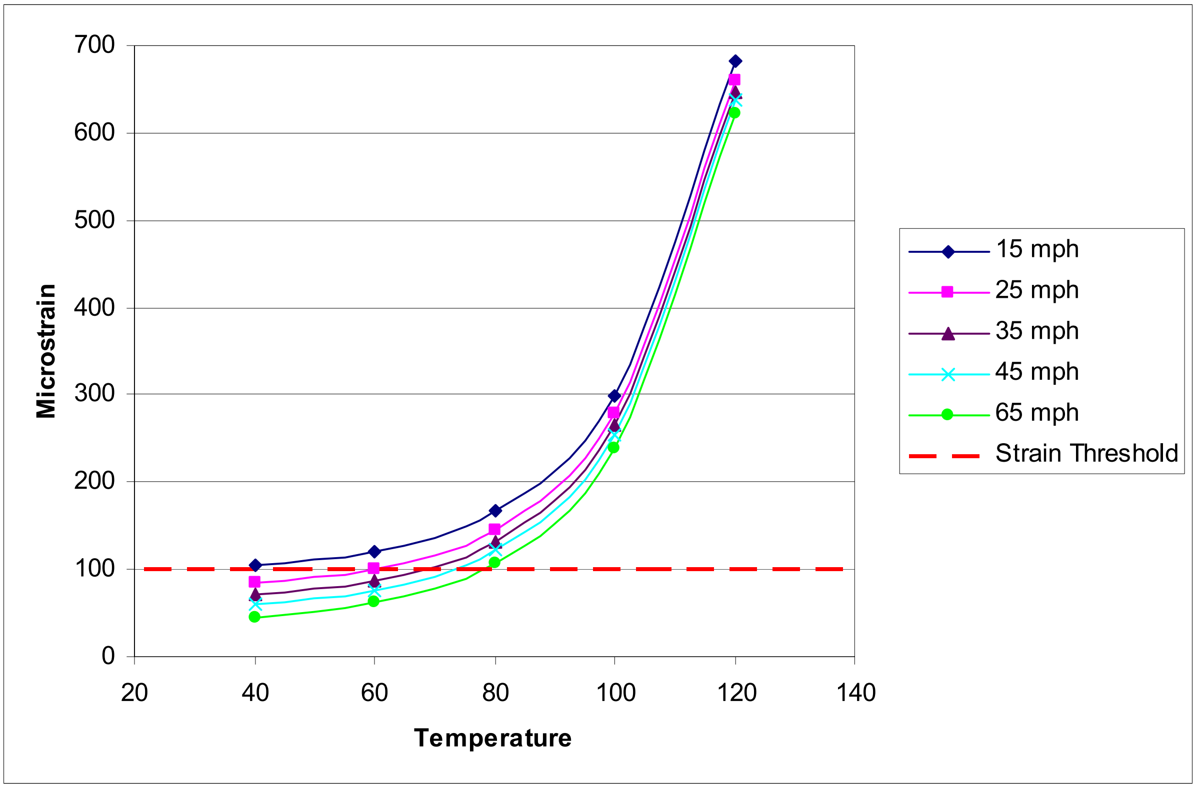

**FIGURE 7 Predicted Strain by Temperature for a Single Axle.**

To investigate the relevance of the laboratory established thresholds, it is important to consider how frequently the critical conditions occur or are surpassed. As noted earlier, section N9 was also subjected to routine traffic at 45 mph for 16 hours per day, 5 days a week, as part of the overall trucking operation for the Test Track. This operation, which commenced in November, 2006 and continued to the end of the Test Track cycle, provided a range of temperatures experienced over a much broader time period. Temperatures were recorded on a minute-by-minute basis from which hourly summaries were stored. From the available temperature data, the average mid-depth temperatures were retrieved from November 7, 2006 to January 14, 2008. Using the regression equation developed above, the tensile strains at the bottom of the HMA were calculated for the recorded temperatures and a vehicle speed of 45 mph.

Figure 8 depicts the calculated longitudinal strain under a single axle for the average mid-depth pavement temperature data (T2_avg) and vehicle speed of 45 mph for the hours of operation (5:00AM to 11:00PM). Using the same regression equation for the longitudinal strain under a single axle, the critical temperature for a vehicle speed of 45 mph was found to be 72.83°F. Figure 8 illustrates that on a large number of occasions mid-depth temperatures far surpassed this critical temperature, with maximum mid-depth temperatures approaching 118°F. Corresponding to these high temperatures were elevated tensile strains well above the strain threshold level of 100 με, with maximum strains near 575 με. For the dataset that spanned shortly over a year, only approximately 55% of the calculated strains fell below the 100 με threshold level. To date, this section has exhibited only minimal amounts of rutting (< 5mm) and no cracking. Given the high strain levels and good performance thus far, it may suggest that the field strain threshold could be greater than 100 με. However, further traffic and testing is certainly warranted to confirm or refute this statement. The strain regression equations developed in this study can be used to further study this test section through the remainder of the trafficking cycle.

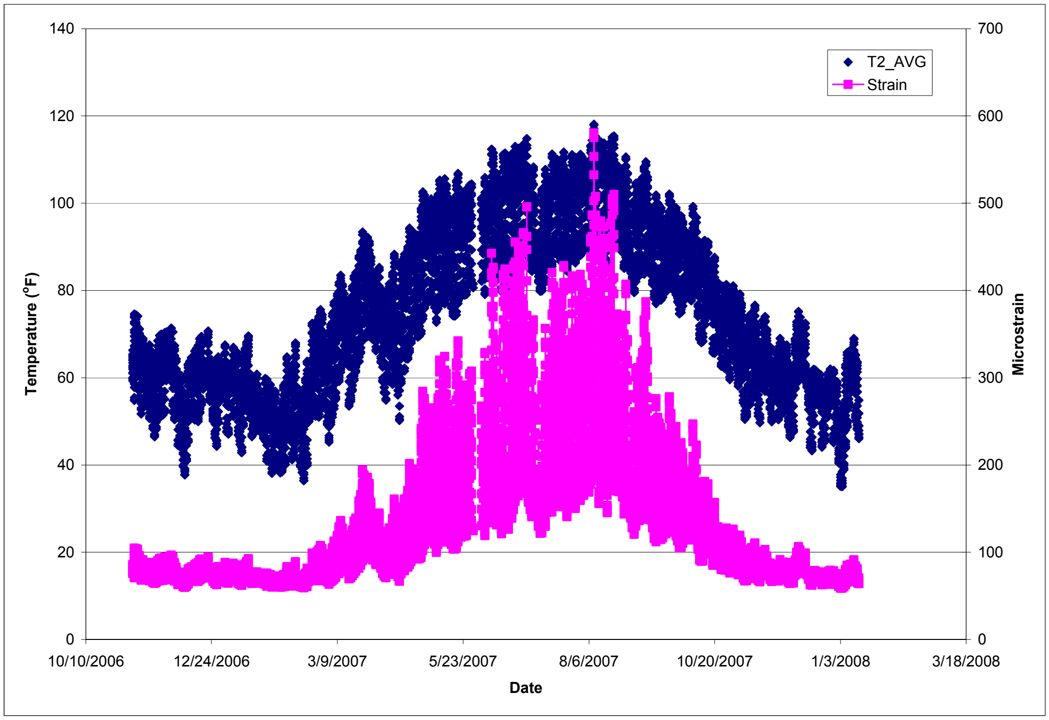

**FIGURE 8 Measured Strain and Mid-Depth Temperatures for the N9 Test Section.**

## SUMMARY

In summary, a perpetual pavement can withstand infinite load repetitions if those applied loads induce strains that fall below a threshold level (*4*). Therefore, it is imperative to be able to predict those strains accurately. One way to increase accuracy is to quantify the effects of two important variables, vehicle speed and pavement temperatures, on pavement response.

Investigations at the NCAT Test Track helped characterize those effects on pavement response for a perpetual pavement section, using the N9 test section. Results from this investigation revealed that increasing the rate of loading, or vehicle speed, caused a substantial reduction in strain levels. It was noted that the rate of strain reduction was more sensitive to vehicle speeds at warmer temperatures. The tensile strain at the bottom of the HMA layer was found to be proportional to the natural logarithm of the vehicle speed. Additionally, the experiment revealed that the mid-depth pavement temperature correlated the best with the induced tensile strain. Further analysis illustrated that increasing the mid-depth temperature resulted in drastic elevations in the tensile strain induced, such that the relationship could be described by an exponential function of the temperature. The combined effects were correlated to the measured strain levels, resulting in a regression equation of the form:

$$y = a \ln x_1 + e^{cx_2} + d$$

The regression equations that were developed for the pavement test section were used to predict strains for various temperatures and speeds, enabling a comparison to a laboratory threshold level of 100 με. This comparison indicated that the critical mid-depth pavement temperature for vehicle speeds of 65 mph or less was approximately 78°F. Generally speaking, for vehicle speeds of 65 mph or less, the strains induced at temperatures greater than this critical temperature will be greater than the threshold level, causing damage to the pavement that must be accounted for. The regression equations were also utilized to estimate the induced strain in the N9 test section under routine trucking operations at the Test Track. For a time period of shortly over a year it was found that less than 55% of the estimated strains were below a threshold value of 100 με. Based on these analyses, monitoring of strain levels and performance should be continued to determine if a threshold level of 100 με is conservative for the N9 pavement section.

## ACKNOWLEDGEMENTS

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