Effects of Pavement Distress on Measured Pavement Response Under Accelerated Loading

Revised Paper Submitted to
3rd International Conference on Accelerated Pavement Testing, 2008
Madrid, Spain
May 29, 2008

Adam Joel Taylor
Graduate Research Assistant
National Center for Asphalt Technology
277 Technology Parkway
Auburn University
Auburn, AL 36830
Phone: (334) 844-6228
Fax: (334) 844-6248
E-mail: tayloa3@auburn.edu

David H. Timm, Ph.D., P.E. (Corresponding Author)
Gottlieb Associate Professor of Civil Engineering
Department of Civil Engineering
238 Harbert Engineering Center
Auburn University
Auburn, AL 36849
Phone: (334) 844-6282
Fax : (334) 844-6290
E-mail: timmdav@eng.auburn.edu

Total Words =
Abstract (246) + Main Text (4,958) + Figures and Tables (9x250) = 7,454

ABSTRACT

Many accelerated pavement test facilities share two common features. First, they are often designed to test pavements from an original condition to a failed state in a relatively short time period. Second, they frequently utilize embedded instrumentation to monitor pavement responses during the testing cycle. These measurements can provide valuable data needed to validate existing mechanistic models and assist in the development of new models. However, as a test pavement begins to show distress due to loading, the measurements have the potential to become erratic and meaningless. Therefore, it is important for researchers to distinguish between so-called "good" and "bad" data. To better understand the interaction between pavement distress and response measurement, fourteen test sections at the National Center for Asphalt Technology (NCAT) Pavement Test Track were investigated. Though each section contained asphalt strain gauges and earth pressure cells, this paper focuses on the vertical pressure measurements. Approximately weekly pressure measurements were made from 2003 until 2007 during which time a range of distresses and severities were observed. Prior to distress, the response measurement was typically a function of temperature. Regression analysis with this variable produced very high R^2 prior to evidence of major distress. After major distresses were evident in many sections, the measured responses became highly erratic and the regression equations were no longer useful. The results of this investigation provide guidance for the effective use of instrumentation under accelerated loading and developed a method for establishing cut-off points between reliable and unreliable data.

INTRODUCTION

Background

Accelerated Pavement Testing (APT) facilities provide an excellent way to conduct performance testing on a complete pavement structure. These facilities allow pavement testing on a smaller and cheaper scale and results are typically achieved over a much shorter time frame than through observation of open highways. Additionally, these facilities can be outfitted with instrumentation at various locations throughout the cross-section of the pavement structure. These devices allow for measurement of several in-situ conditions, such as temperature and moisture, as well as pavement response to applied loading (such as stress and strain) (*1,2*).

Multiple advances in asphalt technology over the last half-century have facilitated a shift from statistically based empirical pavement design methods (e.g. AASHTO) to more mechanistic-empirical methods (e.g. MEPDG) (*3, 4, 5, 6*). M-E design typically utilizes detailed information regarding characterization of pavement materials, environmental conditions, applied traffic loading, and observed pavement performance (*3*). Instrumentation at APT facilities can be used to obtain many of the inputs required for validating mechanistic pavement models at the experimental testing level.

Quality response measurements from instrumentation at APT facilities are required to calibrate and validate mechanistic models for the pavements being tested at these facilities. Studies have shown pavement layer moduli to vary with changing environmental conditions, thus impacting the pavement response under loading (e.g. pavement temperature and moisture) (*3, 7, 8*). Hence, thermistors to monitor changes in pavement temperature with depth and either sub-surface moisture probes or a nearby weather station are often used to quantify the condition of the surrounding environment. Additionally, pavement response data under known loading must be measured accurately to correlate these responses to measured and observed pavement distresses via transfer functions (*3, 4*). These transfer functions are used in conjunction with Miner's Hypothesis to predict the design life of the pavement (*9*). Therefore, accurate pavement response measurements are critical to developing field-calibrated transfer functions which can accurately predict the projected design life of the pavement.

Often, pressure plates are used to measure stresses at critical interfaces in the pavement structure (e.g. interfaces between layers, surface of aggregate base, surface of subgrade) (*1, 2*). Pressure measurements at the surface of the base and subgrade can be related to the performance of the pavement structure through mechanistic modeling (i.e. modeling rut depths) (*10*). These measurements can also be used for the calibration and validation of mechanistic models. In a study conducted by NCAT during the 2003 Test Track research cycle, a falling-weight deflectometer was utilized above the embedded pavement instrumentation. This allowed for comparisons to be made between the measured instrumentation responses and the theoretical layered elastic analysis (LEA) software responses for the given pavement structure (*11*). Since theoretical pavement responses are often generated by backcalculation software, use of this testing procedure can be very helpful in validating pavement cross-sections used in backcalculation of layer moduli.

Since accurate response measurements from pavement instrumentation are vital for successful modeling, the question of how to determine whether or not they are producing accurate readings arises. First of all, it is vital to ensure that the gauges are properly calibrated to ensure functionality prior to installation (*1, 2*). Secondly, care must be taken during installation and paving to protect the gauges to ensure that they survive construction intact (*1, 2*). Finally, careful monitoring is needed to ensure that these gauges continue to function well over time as more and more load repetitions are applied to the pavement. Since APT experiments are typically designed so that pavement distress will occur, it is important to know how the embedded pavement instrumentation will respond as the pavement begins to undergo distress. At this point in the research cycle, one would expect to measure erratic responses since the pavement is no longer completely intact.

Objective

The purpose of this project was to examine the behavior of pavement response instrumentation (specifically pressure plates) in sections exhibiting varying levels of pavement distress. From this investigation, a method of examining the collected instrumentation data and isolating distress effects within that data was established.

Scope

This study was performed at the NCAT Test Track near Auburn, AL. The Test Track is a 1.7 mile closed-access facility with forty-six 200 ft test sections. This project utilized pressure data collected from 8 test sections in the 2003 test cycle and 11 sections in the 2006 test cycle. Each section had two pressure plates, one at the top of the aggregate base and the other at the top of the subgrade. Thermistor probes embedded in each section provided relevant temperature data from which pressure versus temperature regression equations could be developed. Surface performance measurements made on a weekly basis were utilized to correlate response measurements and distress (i.e., pressure and cracking).

TEST FACILITY

Test Sections

The test sections utilized for this study were the eight structural sections (sections containing embedded instrumentation) constructed for the 2003 research cycle and the eleven structural sections utilized for the 2006 research cycle. Sections N3 – N7 were used in both studies, having been left in place at the conclusion of the 2003 experiment. Section N5 underwent a two-inch mill and inlay rehabilitation between the two research cycles. Figure 1 illustrates the structural composition of the various test sections. The figure simply illustrates the variety of pavement layer thicknesses utilized in the structural study. Further details regarding the composition of these sections have been previously documented (*2, 12).*

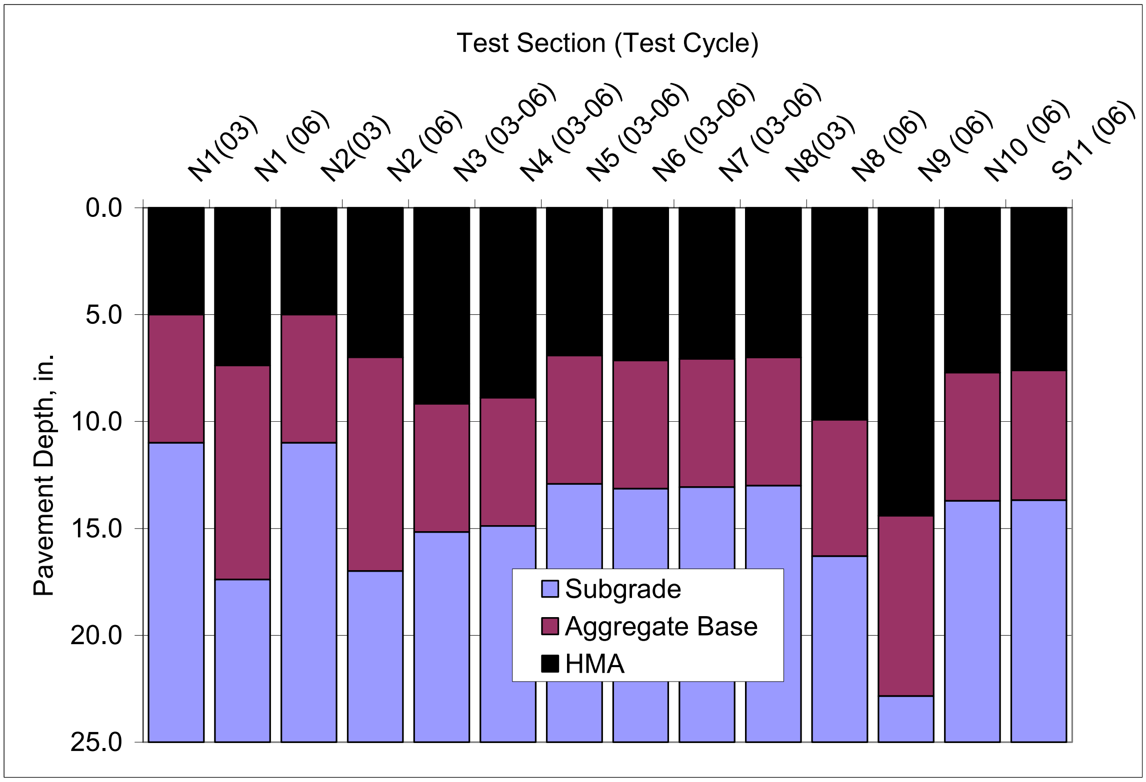


FIGURE 1 Test Track Structural Cross-Sections.

Instrumentation

Pressure measurements were made with the Geokon model 3500 earth pressure cell. Each section shown in Figure 1 had a pressure plate at the top and bottom of the aggregate base layer. Since gauge installation has the potential to affect gauge measurement, a brief description of the installation procedure is provided below.

Great care was taken to ensure that the gauges were properly installed and survived construction intact. For each pressure plate, a shallow cavity deep enough to hold the gauge as well as a trench for the sensor cable were cut into the supporting layer (either the aggregate base or subgrade). In the 2006 installation, the wiring was threaded through a flexible aluminum conduit and placed in the trench running the wire to the roadside data collection box. This was done to protect the gauge wiring from any surrounding base or subgrade material that might cut the wire during compaction of the subsequent pavement layer. In the 2003 installation, no flexible aluminum conduit was used. It should be noted that no difference in pressure gauge survivability was found between the two installations. Both installations had 100% survivability.

The pressure plate cavity was filled with material sieved through a #8 screen (the same material as the supporting layer) and compacted by hand using a Marshall hammer and leveled off. Next a layer of layer material that passed a #16 sieve was placed in the cavity, compacted, and leveled off. Next, the pressure plate was placed in the cavity and pressed into the fill material until level as illustrated in Figure 2. Then, another layer of -#16 material was placed over the gauge followed by a layer of -#8 material. This was done to create a buffer between the pressure plate and the surrounding base or subgrade material, and to ensure that no larger particles within the base or subgrade could puncture the outer wall of the pressure plate. Finally, prior to being placed under the HMA (for the base layer gauges only), a layer of asphalt material taken from the hopper of the paver was screened over a #4 sieve and compacted by hand atop the gauge to ensure both protection from the paver screed and to prevent the paver from shifting the position of the gauge. Finally, the gauges were monitored continuously during construction to ensure survivability.

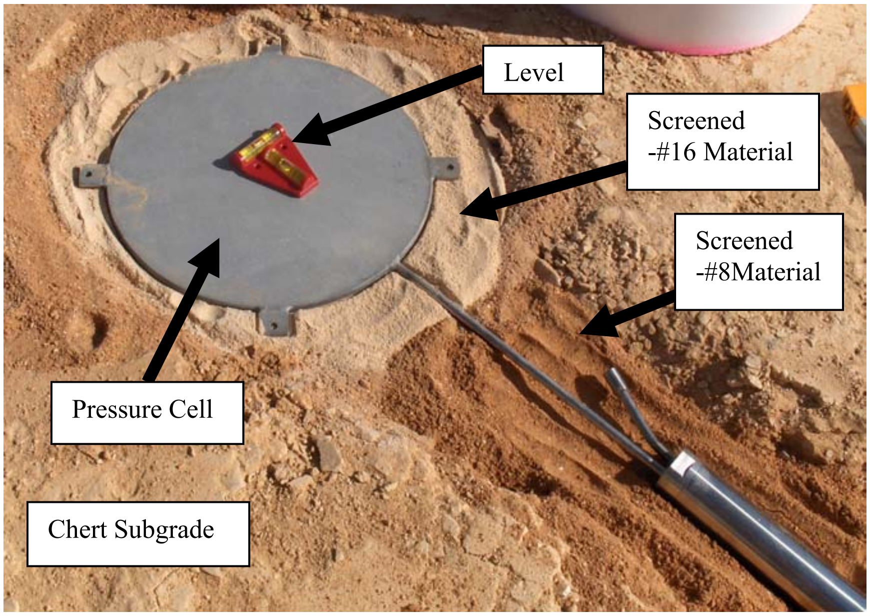


FIGURE 2 Installation of Geokon 3500 EPC at the NCAT Test Track.

The test sections also contained thermistors at various depths throughout the pavement cross section. The thermistors were Campbell-Scientific model 108's bundled together to measure thermal gradients. The 2003 structural sections contained thermistors at the pavement surface, two inches below the surface, four inches below the surface, and ten inches below the surface. The 2006 structural sections contained thermistors at the surface of the pavement, at mid-depth of the HMA layer, at the bottom of the HMA layer, and three inches below the bottom of the HMA. The sensors were installed after construction by drilling a vertical hole into the pavement, coating the thermistor array in roofing cement and inserting it into the hole.

Traffic

Each research cycle of the Test Track is designed to apply 10 million equivalent single axle loads (ESALs) to the test pavement over approximately two years. For the 2003 research cycle, the traffic load was applied to the pavement by a fleet of four triple-trailer trucks and one legally loaded FHWA Class 9 box trailer. The box trailer was not considered in this analysis since it represented a small proportion of the total traffic. For the 2006 research cycle, a fleet of five triple-trailer trucks were used to load the pavement. Each triple-trailer applied a steer axle (12 kips), a drive tandem axle (40 kips), and five trailing single axles (20-22 kips). Vehicle speed was maintained at 45 mph. The vehicles were human operated sixteen hours a day, five days a week.

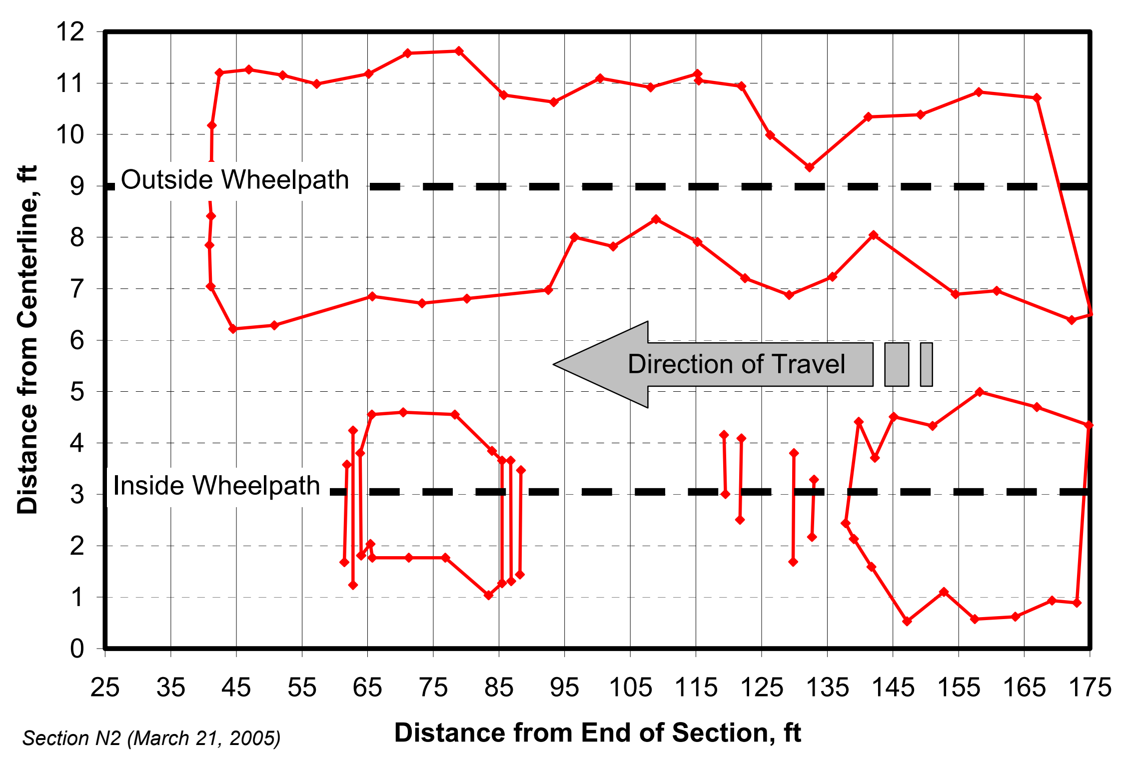
Data Collection and Processing

Pavement response data were collected using high and low frequency methods at the Test Track. The so-called "slow speed" network was designed to collect pavement temperature once per minute and tabulate hourly averages. The "high speed" data acquisition network enabled the collection of dynamic pavement response data under truck traffic at 2,000 Hz per gauge. For data collection, three passes of each truck were collected for each test section. For the 2003 research cycle, data were initially collected from each of the structural sections once per month prior to April 2004, whereupon it was collected weekly afterwards. In the 2006 research cycle, the data were collected on a weekly basis. The data in this paper represent collection efforts from November 10, 2006 through September 27, 2007.

After collecting raw pressure data, each data set was processed using customized data processing software. Details of the data processing methodology for the 2003 research cycle can be found in (*4*). For the 2006 research cycle, a maximum, minimum, and amplitude of the pressure response was processed for the steer and tandem axles for each truck, and for the single axle on each truck that produced the largest pressure response within the pavement.

Crack Detection and Mapping

At the Test Track, traffic was halted each Monday to allow for truck/equipment maintenance and to allow for monitoring of test section performance. For the process of crack detection, the pavement in each test section was carefully inspected and any signs of cracking or cracked areas were marked. Then, a permanent record was taken of the pavement by slowly passing a video camera attached to a boom on a skid-steer tractor over each test section. The video of each test section was then digitized so that the coordinates of the cracking could be determined from the digital record. From this, crack maps were produced that document the performance of each section. An example of a generated crack map for section N2 from the 2003 research cycle is shown in Figure 3. The crack map shows the locations of the distress events with the large enclosed polygons representing an area of interconnected cracking (i.e. alligator cracking), and the single lines represent stand-alone cracks. These maps were used to create an historical record of pavement distress and crack development.



Section N2 (March 21, 2005)

FIGURE 3 Example of Crack Mapping.

METHODOLOGY AND DATA ANALYSIS

To conduct an investigation on the effect of pavement distress on pressure plate readings, several key data sets were required. First, the dates at which significant distresses were witnessed and the type and progression of these distresses needed quantification. Table 1 shows a listing of the major distresses witnessed during performance data collection for both the 2003 and 2006 research cycles, including the type of distress and the date the distress was first observed. Coring and forensic investigation during the experiment were used to confirm the origin of the cracking. Fatigue cracking originated at or near the bottom of the HMA layer while the top-down cracking originated at the surface of the HMA layer (*4, 13*). Therefore, one might expect fatigue cracking to more severely affect gauge readings. Sections not listed in Table 1 do not yet have any substantial distresses.

TABLE 1 Summary of Cracking Events in the Structural Sections

Section	Research Cycle	Major Distress	Date of First Observation
N1	2003	Fatigue Cracking	4/8/2004
N2	2003	Fatigue Cracking	6/21/2004
N5	2003 and 2006	Top-Down Cracking	6/13/2005
N6	2003 and 2006	Fatigue Cracking	10/25/2005
N7	2003 and 2006	Fatigue Cracking	8/2/2005
N8	2003	Fatigue Cracking	7/19/2004
N1	2006	Top-Down Cracking	5/14/2007

For each test section, multiple pressure readings were obtained for each day of data collection. This generated a distribution of pressures collected for each section on a given day. To effectively analyze the data, it was useful to select a "best-hit" from this distribution of pressures and represent these distributions as a single pressure value for each section on a given day. Selveraj utilized the maximum pressure collected on each section over three truck passes as the "best-hit" for his analysis (*10*). For the 2006 pressure data, the 95th percentile pressure value was utilized as the "best-hit" in order to capture the vast majority of the pressure variability but to eliminate any extreme positive outliers from the distribution. Though these are technically slightly different analysis techniques, a comparison between using the 95th percentile and 100th percentile (i.e., maximum) yielded no appreciable differences in the final results.

For quality control purposes, it is important to accurately determine when the gauge readings are no longer trustworthy so as to establish a cut-off point between "good data" and "bad data." The first step in the analysis procedure was to examine how the raw data (pressure and pavement temperature) varied with time. An example of this type of analysis is shown as Figure 4. This figure shows the plot of pressure and pavement temperature (from a thermistor 2" below the pavement surface) versus time for section N3 from the 2003 research cycle, a section that exhibited no major forms of distress. It is evident from the plot that the pressure and temperature readings show the same general trends as time progresses. This type of analysis is useful to pin-point any divergences in these two curves. Such a divergence could be directly related to a pavement distress causing the pressure plate yield unreliable or erratic data.

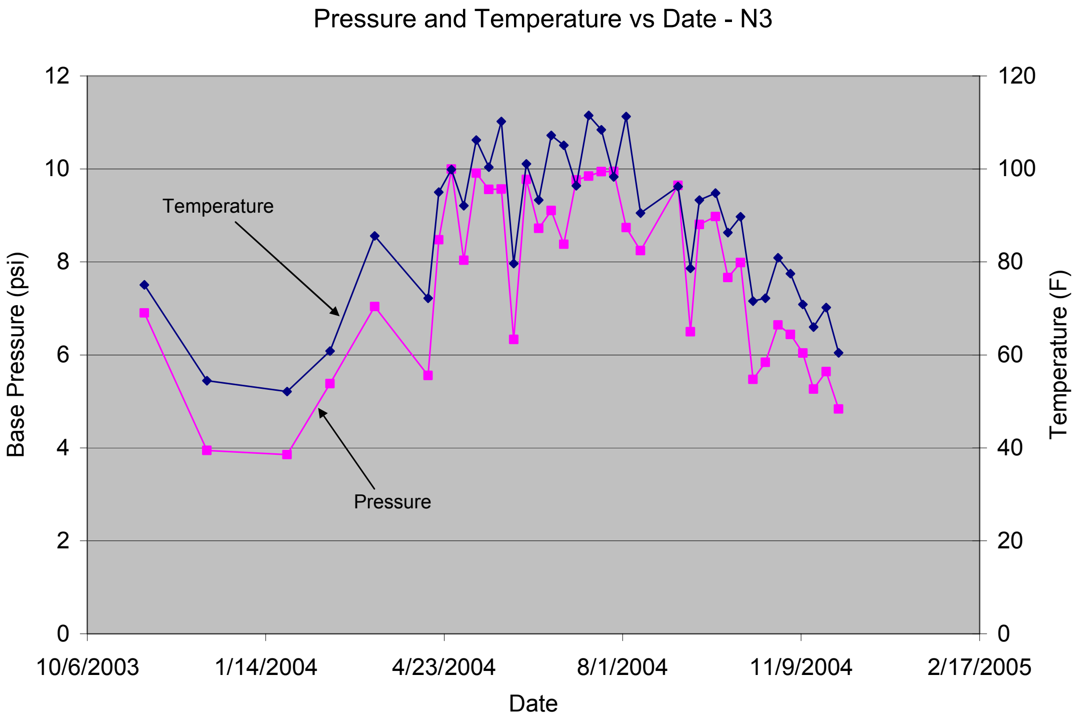


FIGURE 4 Maximum Daily Base Pressure and Temperature vs. Date for Section N3 (2003 Research Cycle).

It is evident from Figure 4 that there is a strong relationship between measured pressure and pavement temperature. This was to be expected since studies have shown that there is a strong correlation between pavement response and various measured temperatures within the HMA layer (*1, 4, 10*). As the temperature increases, the viscosity of the asphalt binder decreases, resulting in a reduced asphalt modulus and an increase in stresses transmitted to the lower layers measured by the pressure plates. An example plot of the temperature-pressure relationship is shown in Figure 5 for the N3 base plate from the 2003 Track. It can be seen from Figure 5 that an exponential function quantifies this relationship well.

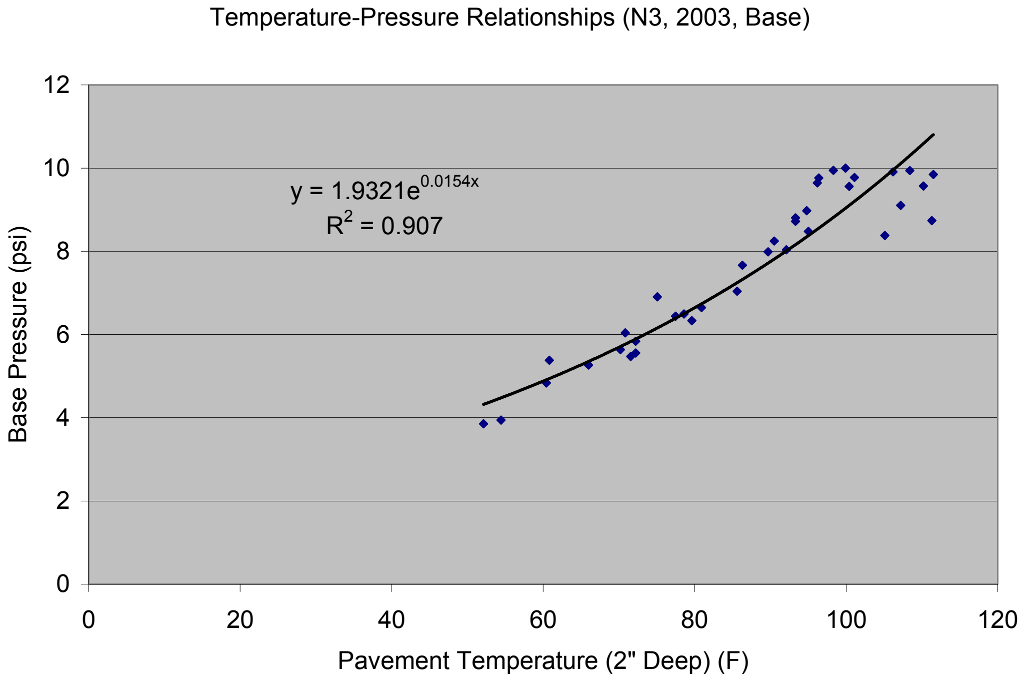


FIGURE 5 Temperature-Pressure Relationship Example.

This relationship can also be a useful tool in determining the functionality of a gauge and whether pavement distress or other factors have caused the gauge to deliver erratic response readings. For each of the structural sections at the NCAT Test Track, an exponential relationship was developed relating pressure to HMA temperature:

$$\sigma = c_1 * e^{(c_2 x)} \qquad (1)$$

The pressures utilized to generate these relationships were derived from the selected “best-hit” pressure for a given day’s data collection. Since there were four thermistors throughout the depth of the pavement structure in each of the structural sections, it was necessary to select an optimal pavement temperature for use in generating the temperature-pressure relationships. For the temperature-pressure relationships generated from the 2003 research cycle data, the HMA temperature 2” below the surface was shown to generate the best correlation between the temperature data and the pressure data (*10*). For the temperature-pressure relationships generated from the 2006 research cycle data, the mid-depth pavement temperature was utilized and provided the strongest relationships. This could be due to having measured, rather than interpolated, mid-depth temperatures available in the 2006 research cycle.

Since the data for the 2006 Test Track were processed by axle rather than by truck, it was necessary to generate a temperature-pressure relationship for each axle type within each section. Table 2 shows a summary of the temperature-pressure relationships generated for each of the structural sections at the NCAT Test Track. For simplicity of data analysis, only the temperature-pressure relationships derived from the single axle induced pressures are reported in Table 2 for the 2006 research cycle. Note that the vast majority of the gauges exhibit a high R^2 value (above 0.7) for the temperature-pressure relationship. However, a handful of the gauges exhibit a very poor model fit. These sections will be investigated in detail in the discussion to follow.

An example of utilizing temperature-pressure relationships to isolate erratic gauge behavior under a major distress is shown by analyzing sections N1, N2, and N8 from the 2003 research cycle. These sections failed via having large amounts of fatigue cracking relatively early in their design lives. Not indicated in the table, but worthy of note, was that each section experienced fatigue to a degree requiring full-depth reconstruction as part of the rebuild for the 2006 experiment. It can be seen from the results in Table 2 that the temperature-pressure relationships for the base and subgrade gauges used in these sections all exhibit relatively low R^2 values (below 0.7). Hence, it seems logical from the large amounts of distress in the section that these distresses had an effect on the instrumentation readings. This is especially true for the base pressure plate, which is at the interface where fatigue cracking typically originates (at the bottom of the HMA layer).

Figure 6 shows the representative temperature and base pressure versus time curves for Sections N1, N2, and N8 from the 2003 cycle. Each of these plots show the "best-hit" pressure reading and the corresponding measured pavement temperature for each data collection period as time progressed. Additionally, the date of first observed distress is indicated on these plots (these dates correspond to the type of distress listed for those sections in Table 1). Each of these plots show that the pressure and temperature curves exhibit the same general trends prior to the major distress being observed within the section, behavior similar to that exhibited in the N3 example shown in Figure 4. However, prior to the date of first observed cracking, the pressure readings began to behave very erratically from week to week. From these plots, it seems likely that the pavement distresses are playing a role in the behavior of the pressure instrumentation.

A closer look at N2 (the middle graph in Figure 6) will be taken to demonstrate how temperature-pressure relationships can be used to establish good data cut-off dates. To attempt to isolate when the gauge was affected, first the weekly crack maps for this section were inspected. The first signs of interconnected surface cracking appeared on 6/21/2004. Therefore, this seemed a logical initial cut-off date for data analysis. A regression analysis of all the temperature and pressure data prior to this date yielded an R^2 value of 0.12. Clearly this was insufficient in determining a cut-off date for the accurate pressure data from this section.

TABLE 2 Summary of Temperature-Pressure Relationships.

Section	Research Cycle	Layer	C_1	C_2	R^2
N1	2003	Subgrade	N/A	N/A	N/A
N1	2003	Base	12.576	0.000	0.00
N2	2003	Subgrade	1.912	0.019	0.61
N2	2003	Base	2.772	0.017	0.14
N3	2003	Subgrade	0.946	0.019	0.96
N3	2003	Base	1.932	0.015	0.91
N4	2003	Subgrade	1.134	0.017	0.84
N4	2003	Base	1.276	0.019	0.93
N5	2003	Subgrade	1.243	0.019	0.97
N5	2003	Base	1.088	0.021	0.96
N6	2003	Subgrade	1.178	0.020	0.95
N6	2003	Base	1.703	0.017	0.76
N7	2003	Subgrade	1.589	0.017	0.96
N7	2003	Base	2.093	0.015	0.88
N8	2003	Subgrade	1.552	0.018	0.50
N8	2003	Base	3.902	0.010	0.21
N1	2006	Base	2.774	0.018	0.82
N1	2006	Subgrade	1.291	0.019	0.85
N2	2006	Base	4.026	0.015	0.74
N2	2006	Subgrade	1.496	0.016	0.88
N3	2006	Base	2.572	0.016	0.97
N3	2006	Subgrade	1.446	0.018	0.82
N4	2006	Subgrade	1.269	0.017	0.99
N5	2006	Base	1.967	0.017	0.94
N5	2006	Subgrade	3.453	0.009	0.80
N6	2006	Base	2.901	0.017	0.90
N6	2006	Subgrade	3.788	0.009	0.68
N7	2006	Base	4.734	0.011	0.86
N7	2006	Subgrade	8.253	0.001	0.09
N8	2006	Base	1.871	0.020	0.93
N8	2006	Subgrade	0.943	0.020	0.98
N9	2006	Base	1.115	0.016	0.87
N9	2006	Subgrade	0.955	0.012	0.82
N10	2006	Base	1.908	0.023	0.92
N10	2006	Subgrade	0.391	0.034	0.95
S11	2006	Base	1.636	0.023	0.89
S11	2006	Subgrade	1.683	0.019	0.89

The next step in the analysis procedure was to analyze the plot of pressure and temperature versus date for this section shown in Figure 6. This figure shows that the pressure readings start to exhibit a different behavioral trend from the temperature readings after a collection date in early March, not long before the first observed fatigue cracking at the surface of the pavement. Soon after this divergence, the pressure readings started to behave quite erratically from week to week. This data point was traced back to a collection date on 3/15/2004. Prior to this date the plots of pressure and HMA temperature versus time seem to exhibit the same general trend. A temperature-pressure relationship using only the data before this cut-off date was generated, yielding an R^2 value of 0.61. While still not ideal, the data prior to the cut-off date seem to behave reasonably.

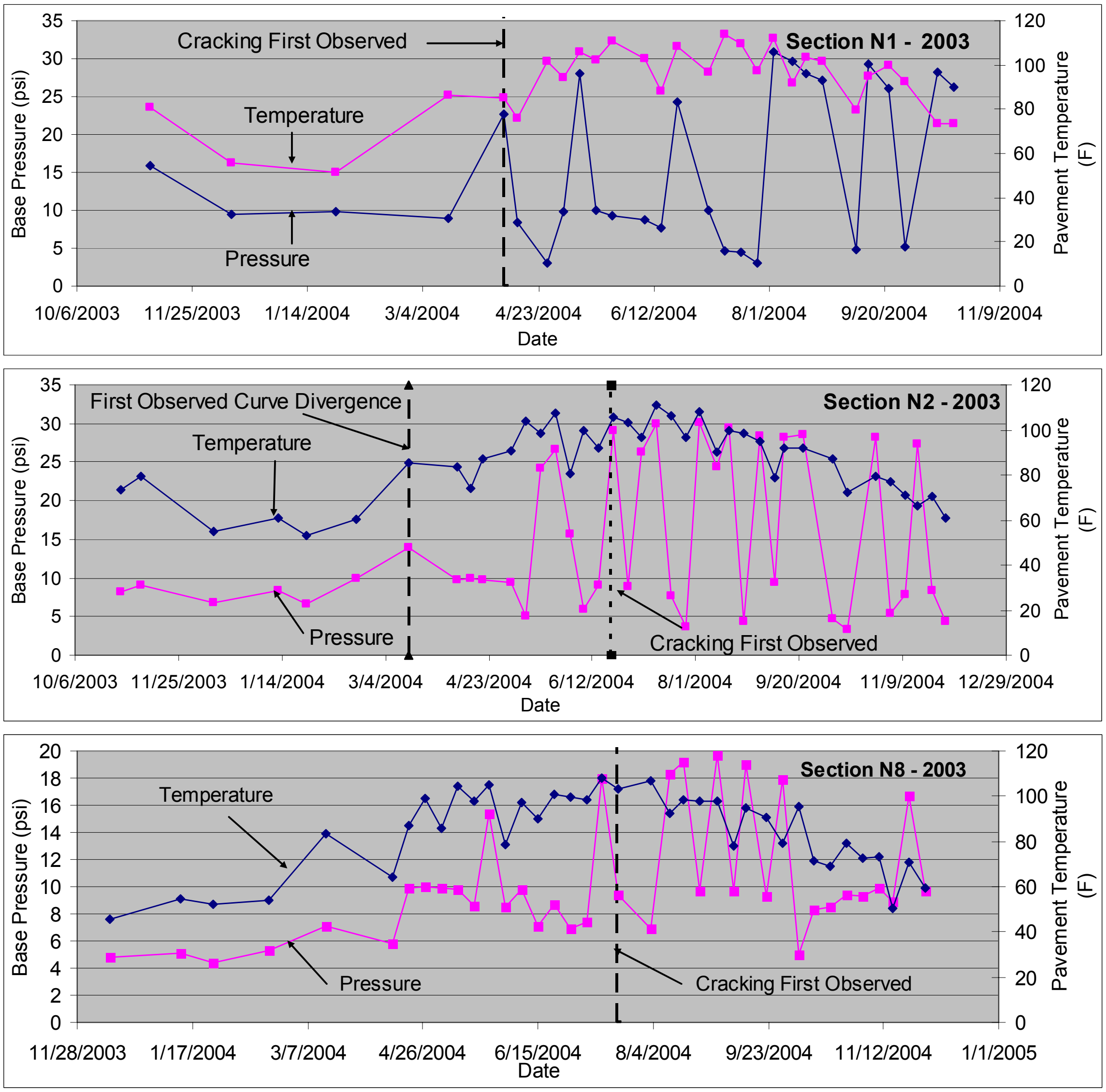


FIGURE 6 Examples of Erratic Pressure Plate Behavior in Test Sections Showing Pavement Distress.

Two key points can be made from this analysis. First, seeing no signs of distress at the surface of the pavement does not necessarily mean that distress is not having a critical effect on the gauge array. For example, fatigue cracking originates at the bottom of the HMA layer and works its way upward through the pavement structure. This distress type could cause a pressure plate to generate erratic readings unbeknownst to whoever is monitoring the data. Therefore, it is vital to maintain a close watch on collected and processed data to look for any signs of erratic behavior. Utilizing the aforementioned analysis techniques to check the viability of a data set is recommended prior to using the entirety of the data set for other forms of analysis.

It is very important to collect as much data as possible at the beginning of a testing cycle, especially for test sections designed to exhibit distress early in their design life. Analyzing the temperature-pressure relationships from section N2 of the 2003 research cycle illustrate this point. For the temperature-pressure relationship from the subgrade gauge, an R^2 value of 0.60 was initially calculated. However, the pressure database only contained readings from six data collection days for this section prior to that gauge going off-line. Hence, the low R^2 could be more a function of lack of data to build a relationship rather than erratic gauge behavior. A similar argument can be made for why the temperature-pressure relationship for the base layer prior to the cut-off date has a lower R^2 value. As previously mentioned, at the start of the 2003 research cycle, data were only collected from these sections on a monthly basis. Looking back, it seems that this was an insufficient collection interval given the relatively small amount of data collected prior to the cut-off date. Therefore, frequent data collection in the early stages of accelerated loading is imperative to ensure sufficient data from the test sections are collected. This argument can also be applied to section N1 which only had four collection dates prior to crack initiation which, under the best conditions, can be challenging to build a model. The data from these four dates, as shown in Table 2, exhibited no relationship between temperature and pressure.

The preceding discussion has illustrated how pavement distress can have a significant impact on measured pressure responses. However, witnessing pavement distress at the surface of a test section does not necessarily mean that the embedded instrumentation are providing erratic readings. The Test Track provides several good examples of this. Table 1 shows that sections N5, N6, and N7 (sections left in-place for the duration of two research cycles) all exhibited signs of distress (either top-down or fatigue cracking) prior to the beginning of traffic for the 2006 research cycle. It must be noted that these sections were in sufficiently good condition, however, to continue trafficking in 2006. Additionally, section N1 in 2006 showed multiple interconnected surface cracks beginning to propagate early in its design life (section opened to traffic on 11/10/2006, cracking witnessed on 5/14/2007). This section seemed a prime candidate for erratic gauge readings due to the volume of cracking.

Though these test sections appear to show a significant amount of distress, no convincing evidence could be obtained to indicate that the gauges from these sections are giving erratic readings. Table 2 shows that the temperature-pressure relationships for these sections demonstrate moderate to excellent R^2 values (with the exception of the subgrade gauge N7, which will be discussed later). Figure 7 shows the plots of representative pressure and temperature versus collection date for the base gauges for Sections N1, N5, N6, and N7 for the 2006 research cycle. The figure shows no clear divergence of the pressure curve from the temperature curve as time progresses for any of these sections. Therefore, it seems the witnessed distresses from these sections are not having a direct effect on the pressure cell measurements, as of yet. However, it is necessary that the data from these sections be continually monitored in the event that these distresses eventually cause the embedded pressure gauges to behave erratically.

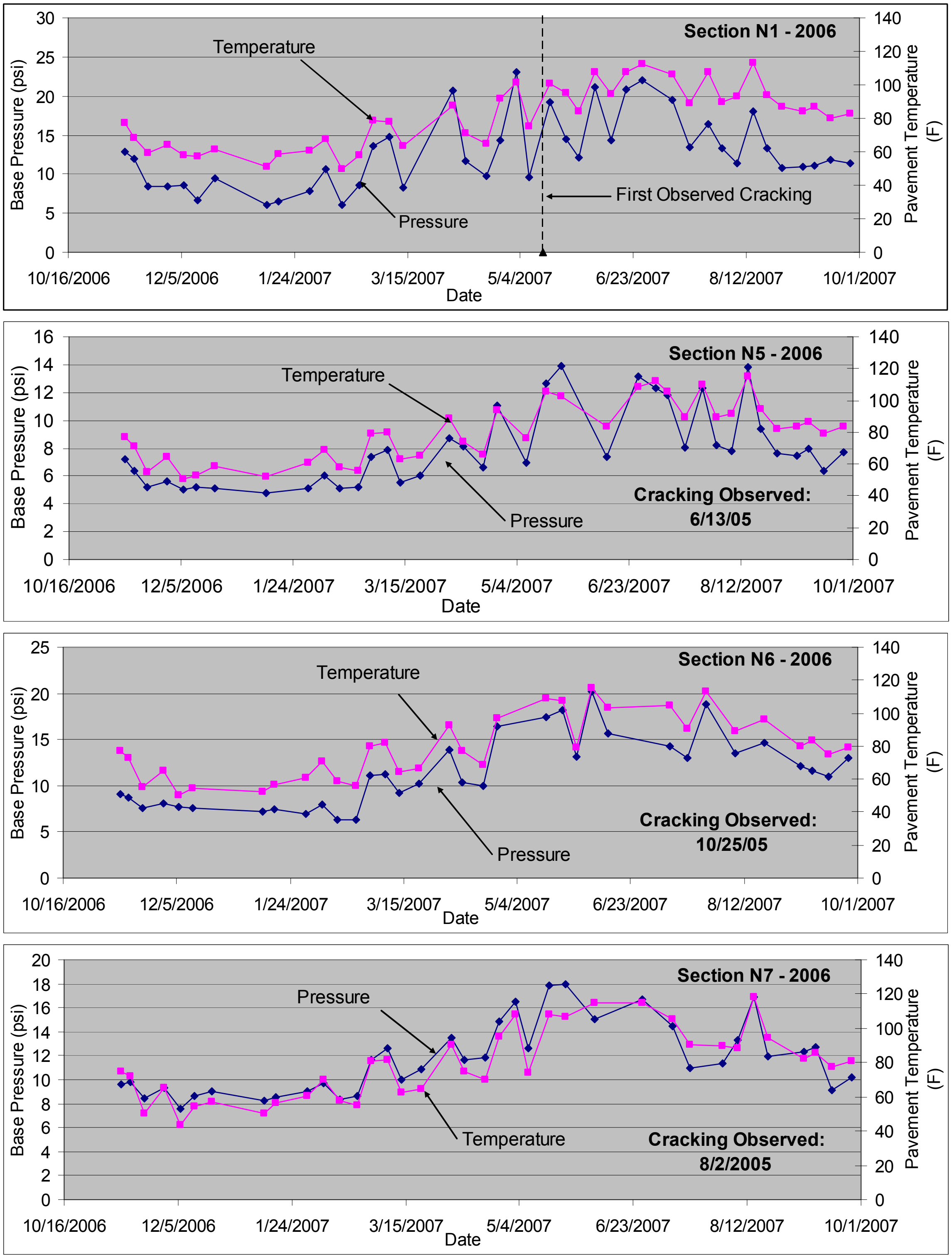


FIGURE 7 Examples of Distress Showing No Effect on Measured Response.

A low R^2 value from the derived temperature-pressure relationship does not necessarily mean that pavement distress is causing erratic gauge readings. Sometimes, the gauge itself is the source of the erratic readings. A prime example of this was illustrated by analyzing the behavior of the subgrade gauge in section N7 for the 2006 cycle. This gauge shows a very poor R^2 value of 0.09 in the temperature-pressure relationship. The gauge in question was installed in 2003 and was left in-place. The section itself also started to show increasing deterioration and cracking in recent months. However, the root of the problem was discovered upon checking one of the raw pressure traces collected from this section in the summer of 2007.

The raw pressure trace collected from this section on July 18, 2007 showed that the majority of the axle passes generated a pressure spike that caused the voltage to exceed the maximum rating of the gauge (14.5 psi). These readings are not accurate since they did not achieve the maximum pressure placed on the gauge by the truck loading. Therefore, it appears that higher pressures later in the design life of the pavement combined with a pressure plate incapable of reading the measured pressures resulted in a poor temperature-pressure relationship for this section. Consequently, the data from this pressure plate were deemed unusable.

CONCLUSIONS AND RECOMMENDATIONS

Data collected from instrumentation in accelerated pavement testing facilities can be very useful for the purposes of better quantifying pavement material performance and establishing better agreement between theory and practice in asphalt construction. Accurate pressure readings from these sections can be very useful in mechanistic modeling of pavement performance. However, it is important to take steps to ensure that the data collected from pressure plates within these facilities are reliable and accurate. This same argument can and should be applied to any instrument used in pavement response monitoring.

Based on the study conducted at the NCAT Test Track regarding pressure data collection over the 2003 and 2006 research cycles, the following conclusions are evident:

- Analysis of the temperature-pressure relationship using the representative pressure value for a given day's data collection and a representative HMA temperature can provide a good measure of gauge behavior. A low R^2 value from these relationships provides a potential indicator of gauge malfunction or pavement damage. A reasonable cut-off for model R^2 appears to be approximately 0.7.
- Analysis of the temperature and pressure versus date plots for a given pavement can provide an indication of when a pressure plate begins to behave erratically. These curves should show the same general trends as time progresses due to temperature and pressure being directly related. Divergence of these curves from one another or highly erratic pressure values can be used to establish a cut-off point between "good data" and "bad data."
- Witnessing pavement distress at the surface does not necessarily mean that the distress negatively impacts the instrumentation below the surface of the pavement.
- Frequent data collection early in the lifespan of test pavements is advisable to collect sufficient data prior to pavement distress causing erratic gauge behavior. This is especially important in test pavements designed to fail early in the loading cycle.

- Continuous evaluation of the test data using good quality control methods is advisable to determine whether or not the embedded instrumentation continues to give accurate readings.

ACKNOWLEDGMENTS

The authors of this paper would like to thank the state departments of transportation from Alabama, Florida, Indiana, Missouri and Oklahoma for their support and cooperation with this research. The Federal Highway Administration also deserves recognition for their support and cooperation.

REFERENCES

1. Al-Qadi, I., A Loulizi, M. Elseifi, and S. Lahouar. The Virginia Smart Road: The Impact of Pavement Instrumentation on Understanding Pavement Performance. *Journal of the Association of Asphalt Paving Technologists*, Vol. 73, 2004, pp. 427- 466.
2. Timm, D.H., A.L. Priest, and T.V. McEwen. *Design and Instrumentation of the Structural Pavement Experiment at the NCAT Test Track.* Report No 04-01, National Center for Asphalt Technology, Auburn University, 2004.
3. Monismith, C.L. Analytically Based Asphalt Pavement Design and Rehabilitation: Theory in Practice, 1962-1992. *Transportation Research Record: Journal of the Transportation Research Board, No. 1354*, TRB, National Research Council, Washington, D.C., 1992, pp. 5-26.
4. Priest, A.L. and D.H. Timm. *Methodology and Calibration of Fatigue Transfer Functions for Mechanistic-Empirical Flexible Pavement Design.* Report No 06-03, National Center for Asphalt Technology, Auburn University, 2006.
5. American Association of State Highway and Transportation Officials. *AASHTO Guide for Design of Pavement Structures.* Washington, D.C., 1993.
6. Eres Consultants Division (2004). *Guide For Mechanistic-Empirical Pavement Design of New and Rehabilitated Pavement Structures*. Final Report, NCHRP 1-37A.
7. Parker, F. Estimation of Paving Materials Design Moduli from Falling Weight Deflectometer Measurements. *Transportation Research Record: Journal of the Transportation Research Board, No. 1293*, TRB, National Research Council, Washington, D.C., 1991, pp. 42-51.
8. Briggs, R.C. and E. O. Lukanen., "Variations in Backcalculated Pavement Layer Moduli in LTPP Seasonal Monitoring Sites," *Nondestructive Testing of Pavements and Backcalculation of Moduli: Third Volume, ASTM STP 1375,* S.D. Tayabji and E.O. Lukanen, Eds., American Society for Testing and Materials, West Conshohocken, PA, 2000.
9. Miner, M.A. Estimation of Fatigue Life with Emphasis on Cumulative Damage. *Metal Fatigue*, edited by Sines and Wiseman, McGraw Hill, 1959, pp 278-89.
10. Selveraj, S.I. *Development of Flexible Pavement Rut Prediction Models from the NCAT Test Track Structural Study Sections Data.* PhD. Dissertation. Auburn University, 2007.
11. Timm, D.H. and A.L. Priest. *Material Properties of the 2003 NCAT Test Track*

Structural Study. Report No 06-01, National Center for Asphalt Technology, Auburn University, 2006.

12. Willis, J.R. and D.H. Timm. *Repeatability of Asphalt Strain Measurements Under Full Scale Dynamic Loading.* Presented at the 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
13. Willis, J.R. and D.H. Timm. Forensic Investigation of Debonding in Rich Bottom Pavement. *Transportation Research Record: Journal of the Transportation Research Board, No. 2040*, TRB, National Research Council, Washington, D.C., 2007, pp. 107-114.