A Systematic Approach to Applying Seasonal Load Restrictions

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ABSTRACT

Weigh-in-Motion sensors and environmental and structural instruments are being used by many state departments of transportation not only to monitor traffic, but also to evaluate the effect of different factors including traffic, temperature and strain on the life of pavement. A significant amount of information on instrumented test sections is available from test sites such as MNRoad, VA Smart road and NCAT, which continue to provide valuable information regarding different aspects of pavement design and performance.

All pavement sections, however, are traversed by unique combinations of traffic during distinct temperature conditions. While general conclusions from an instrumented asphalt pavement test section in one state are applicable to other states, the unique combinations of temperature and traffic in any state call for state-specific data, such as seasonal load restrictions, when making policy decisions which impact the life of pavement, such as seasonal load restrictions.

Many miles of low to medium volume roads in the state of Maine are traversed by heavy trucks, a large percentage of which transport logs for the forest product/paper industry, and these trucks have unique combinations of axle/wheels and trailers that are not commonly found in other states. Additionally, Maine experiences a pronounced fluctuation of temperature throughout the year.

This study gathered traffic, environmental and pavement strain data on a section of Route 15 in Guilford, Maine with the following objectives: 1. To determine the traffic type and load distribution across different months; 2. To develop a model to predict pavement temperature at the location of critical strains; 3. To evaluate the effect of temperature on tensile strain in an asphalt pavement layer; 4. To develop a policy for placing and lifting the State of Maine’s seasonal load restrictions.

This paper presents a sample of the data gathered, the analysis method employed, and suggests a systematic approach to using the data to determine appropriate times for placing and lifting of seasonal load restrictions based on environmental conditions, to minimize damage to the pavement and maximize pavement life. Since the data and observed performance can also be used to estimate the contribution of traffic in different seasons toward the damage of the pavement, both can be used to approximate the life expectancy of a pavement through rational means.

INTRODUCTION

Tensile strain at the bottom of the asphalt mix layer is related to bottom-up fatigue cracking in asphalt pavements. Higher strains lead to an earlier onset of fatigue cracking. The behaviors of an asphalt mix are significantly affected by temperature. Therefore increases in temperature lead to a higher strain for the same traffic load, where temperature remains constant, increases in the traffic load lead to a higher strain. For this reason estimating the effects of traffic and temperature on the pavement is important. This knowledge leads to a better understanding of the effect of traffic loads on the pavement in regions which experience significant climactic changes throughout the year, hence helping in formulating rational plans for load restrictions which aim to minimize the damaging effects of the traffic load on the pavement structure based on the air temperature.

Transporting heavier loads is more efficient for the trucking industry, but is believed to cause more damage to the roads. This increase in damage however, is not experienced during the colder months. Maximizing the days the trucking industry can haul heavier loads, while not reducing the expected life of the pavement requires a review of unique local traffic and temperature conditions and the effect the combination of these local conditions have on the pavement structure.

Weigh-in-Motion sensors, and environmental and structural instruments are being used by many state departments of transportations to monitor traffic and evaluate the effect of different factors on the life of pavement. A significant amount of information on instrumented test sections is available from test sites such as MNRoad, VA Smart road and NCAT, which continue to provide valuable information regarding different aspects of pavement design and performance. The state of Maine recently installed an instrumented pavement section. Maine has many miles of low to medium volume roads that are traversed by heavy trucks, a large percentage of which transport logs for the forest product/paper industry. Many of these trucks have unique combinations of axle/wheels and trailers that are not commonly found in other states. Additionally, Maine experiences a pronounced fluctuation of temperature throughout the year.

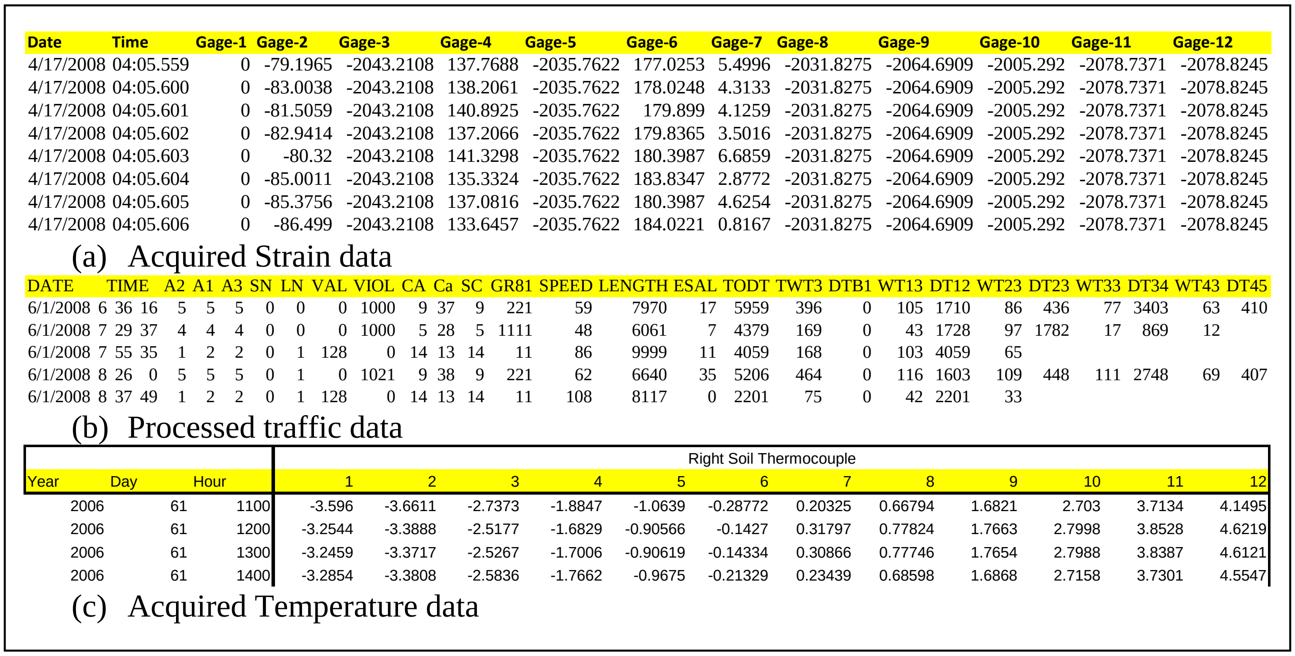
While general conclusions from an instrumented asphalt pavement test section in one state are applicable to other states, the unique combinations of temperature and traffic call for the use of test sections in every distinctive region to impose seasonal load restrictions. The approach taken by any state to gather data and implement seasonal load restriction, as well as that state’s lessons learned can help a region which plans to undertake the same process.

OBJECTIVE

The objective of this paper is to present an approach to gathering and analyzing data to formulate regional policy for determining appropriate guidelines for the imposing and lifting of seasonal load restrictions. The approach presented herein was developed using data from the state of Maine. Data gathered included temperature, traffic, and pavement strain. Using this data, an approach to develop models for predicting pavement temperature and strain, as well as repetitions to failure, with the expressed purpose to minimize damage to the pavement and maximize pavement life, have been presented. The data and observed performance can be used to estimate the contribution of various traffic loads in different seasons toward the damage of the pavement; therefore can be used to approximate the life expectancy of a pavement through rational means. It is the objective of this research that one will use the models and approaches presented in this paper to set an expected pavement life and systematically impose load restrictions based on the expected pavement life.

DESCRIPTION OF TEST SECTION AND INSTRUMENTATION

The instruments used for the test section of Route 15 in Guilford, Maine consist of Weight-in-Motion (WIM) sensor, thermocouples at different pavement depths, and strain gages at the bottom of the asphalt mix base. Mallick details the test section instrumentation in *"Analysis of Pavement Response Data and Use of Nondestructive Testing for Improving Pavement Design and Adoption of Mechanistic-Empirical Pavement Design Procedure Using the Gilford Route 15 Instrumented Pavement Test Section: First Annual Report"* (Mallick 2006). The data gathered through the instrumentation is acquired and stored using on-site computers. Data is then transferred from the MDOT Augusta office through the MDOT network system and an external website to researchers for observation and analysis. An example of the data gathered is shown in Figure 1.



Date	Time	Gage-1	Gage-2	Gage-3	Gage-4	Gage-5	Gage-6	Gage-7	Gage-8	Gage-9	Gage-10	Gage-11	Gage-12
4/17/2008	04:05.559	0	-79.1965	-2043.2108	137.7688	-2035.7622	177.0253	5.4996	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245
4/17/2008	04:05.600	0	-83.0038	-2043.2108	138.2061	-2035.7622	178.0248	4.3133	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245
4/17/2008	04:05.601	0	-81.5059	-2043.2108	140.8925	-2035.7622	179.899	4.1259	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245
4/17/2008	04:05.602	0	-82.9414	-2043.2108	137.2066	-2035.7622	179.8365	3.5016	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245
4/17/2008	04:05.603	0	-80.32	-2043.2108	141.3298	-2035.7622	180.3987	6.6859	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245
4/17/2008	04:05.604	0	-85.0011	-2043.2108	135.3324	-2035.7622	183.8347	2.8772	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245
4/17/2008	04:05.605	0	-85.3756	-2043.2108	137.0816	-2035.7622	180.3987	4.6254	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245
4/17/2008	04:05.606	0	-86.499	-2043.2108	133.6457	-2035.7622	184.0221	0.8167	-2031.8275	-2064.6909	-2005.292	-2078.7371	-2078.8245

(a) Acquired Strain data

DATE	TIME			A2	A1	A3	SN	LN	VAL	VIOL	CA	Ca	SC	GR81	SPEED	LENGTH	ESAL	TODT	TWT3	DTB1	WT13	DT12	WT23	DT23	WT33	DT34	WT43	DT45
6/1/2008	6	36	16	5	5	5	0	0	0	1000	9	37	9	221	59	7970	17	5959	396	0	105	1710	86	436	77	3403	63	410
6/1/2008	7	29	37	4	4	4	0	0	0	1000	5	28	5	1111	48	6061	7	4379	169	0	43	1728	97	1782	17	869	12	
6/1/2008	7	55	35	1	2	2	0	1	128	0	14	13	14	11	86	9999	11	4059	168	0	103	4059	65					
6/1/2008	8	26	0	5	5	5	0	1	0	1021	9	38	9	221	62	6640	35	5206	464	0	116	1603	109	448	111	2748	69	407
6/1/2008	8	37	49	1	2	2	0	1	128	0	14	13	14	11	108	8117	0	2201	75	0	42	2201	33					

(b) Processed traffic data

			Right Soil Thermocouple											
Year	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12
2006	61	1100	-3.596	-3.6611	-2.7373	-1.8847	-1.0639	-0.28772	0.20325	0.66794	1.6821	2.703	3.7134	4.1495
2006	61	1200	-3.2544	-3.3888	-2.5177	-1.6829	-0.90566	-0.1427	0.31797	0.77824	1.7663	2.7998	3.8528	4.6219
2006	61	1300	-3.2459	-3.3717	-2.5267	-1.7006	-0.90619	-0.14334	0.30866	0.77746	1.7654	2.7988	3.8387	4.6121
2006	61	1400	-3.2854	-3.3808	-2.5836	-1.7662	-0.9675	-0.21329	0.23439	0.68598	1.6868	2.7158	3.7301	4.5547

(c) Acquired Temperature data

Figure 1. Samples of data gathered for analysis.

SUGGESTED APPROACH TO DETERMING LOAD RESTRICTIONS

Step 1: Identify a test site which is representative of the region.

Careful consideration should be given when identifying a site for instrumentation. The results and analysis from any instrumented pavement section are most appropriate for the specific pavement section or similar pavement section (structural section) with similar traffic and environment. With this in mind, a test site should be chosen which is representative of the region in question. Furthermore, the test site should be located relatively close to the office where study participates are based. Frequent site visits may be necessary to monitor equipment. The site should not be chosen merely because the road is due to be reconstructed.

The Maine test section with the result presented herein, is built on reclaimed asphalt pavement layer and is a fully reconstructed pavement. It is relatively unaffected by freeze thaw conditions, and has an artificial “stiff” base (the reclaimed layer) which makes this pavement somewhat “unique” and hence the results somewhat inapplicable for other pavements in the region.

Step 2: Collect and process data from the instrumented pavement test section.

To minimize data analysis time, great care should be taken not only in the selection of the test site, but also in the selection and installation of the data collection system. During the Maine study, the utilization of a multi-brand and multi-computer data acquisition systems caused system crashes often, and made it difficult, if not impossible, to match traffic-temperature-strain data. Many of the instruments and sensors were dead by the time the data acquisitions systems were finalized.

When possible, data collection systems should be synchronized in one program to allow for the traffic, temperature and strain data to have identical date and time stamps. Additionally, data collection in one system will allow for more affective data processing, as the multiple data files shown in Figure 1 would be one file with multiple columns.

Temperature data was obtained at three different pavement depths. Air temperature was also gathered as the pavement test site. Historic air temperature data for Guilford, ME was gathered from the National Oceanic and Atmospheric Administration (NOAA) website. (NOAA 2008) Site temperatures files and NOAA files were text files which were converted to Microsoft Excel for analysis.

Strain data was obtained through gauges at the base of the asphalt pavement layer, in ascii format and then opened in excel for analysis. The relevant strain data is as follows, all for Class 10 second axle traffic

Traffic data was collected using a Weight in Motion sensor (WIM). The WIM collects data for every vehicle which crosses the sensor. The vehicle information captured includes axle spacing, vehicle weight per axle, vehicle speed and the date and time the vehicle passes the recording location. The weight is stored by the axle number. For example, if a vehicle with four axles crosses the WIM, the weight for the first axle will be stored in the field for axle 1, the weight for the second axle in the field for axle 2, etc. If a vehicle with two axles crosses the WIM, the weight for the first axle will also be stored in the field for axle 1 and the weight for the second axle will be stored in the field for axle 2. Therefore, one would expect to see every vehicle register a weight in the fields for axles 1 and 2 because cars through large trucks have a minimum of two axles. However, only very large trucks have five or six axles and would register axle weights in those corresponding fields.

The unrefined WIM data was processed using MIRA software into text files. These text files are further processed during the script developed as part of this research. This script analyzed data within the text files and transferred the dataset to Microsoft excel files, by month, for further analysis. The script also allowed for days where data was not gathered to be marked in the excel sheet as an empty day. There are some days that traffic data is not gathered. This could be due to equipment failure or it is remotely possible, although unlikely, that no traffic traveled this section of road during those days.

Step 3: Analyze data from the instrumented pavement test section.

Traffic data analysis included four specific reviews of the traffic data to determine the following:

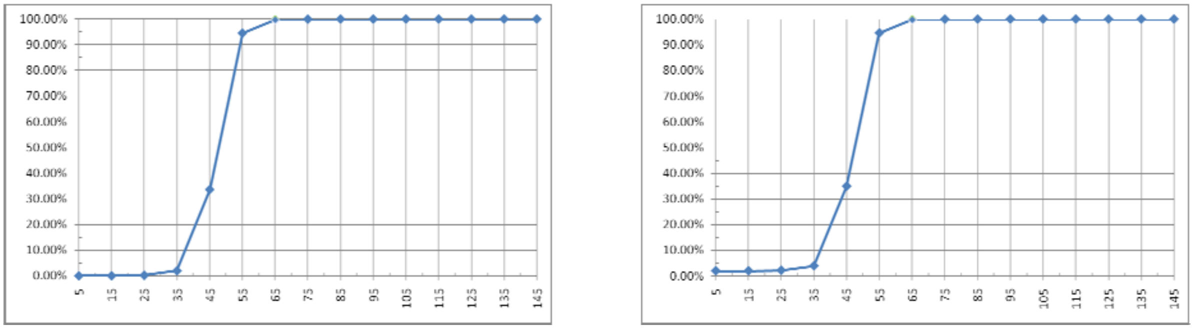
1. The 85th percentile speed;
2. The distribution of traffic volume by week, by day and by hour;
3. The number of vehicles, by vehicle class, for the different months to identify peak traffic months; and
4. The distribution of weight per axle to identify the magnitude and frequency of loads the larger vehicle classes are carrying.

The WIM data includes speed data for each vehicle. This data was collected at one location and can be considered a “spot speed study.” Due to the nature of traveling vehicles (e.g., drivers vary their speed), statistical analysis is conducted on the speed data to determine the speed characteristics which can be applied to the entire population of vehicles traveling that given section of road. One of the most common forms of statistical analysis is a frequency distribution. This frequency distribution plots the cumulative percentage of vehicles traveling at a given speed verses a midpoint of a range of the speeds traveled. From there, the 85th percentile speed can be determined. It is common practice to post the speed limit of a road with the roads 85th percentile speed. The 85th percentile speed is the speed at which 85% of the vehicles are traveling at or below.

This analysis was conducted to determine if the 85th percentile speed for the study road matches the posted speed limit and determine a design speed for further design and analysis. 79,344 vehicles passed through this section of Route 15, Gilford, ME in October, 2007. Recorded vehicle speeds ranged from 11 miles per hour (mph) to 147 mph during the same month. The posted speed is 50 mph.

Of the 79,344 recorded observations, 1,530 had a recorded speed of 0 mph. While zero speed is possible for a parked vehicle, it is unlikely 1,530 vehicles parked over the sensor during one month on this roadway and would indicate perhaps the vehicles were traveling very slowly or the data gathering equipment malfunctioned.

A frequency distribution of the vehicle speeds was conducted to determine the 85th percentile speed. This frequency distribution was conducted both included and excluding the zero speed readings. This distribution is shown in Figure 2.



(a) Including zero speed vehicles.

(b) Excluding zero speed vehicles.

Figure 2. Frequency distribution of vehicle speeds.

The 85th percentile speed when the zero speeds are included is equal to approximately 54 mph. The 85th percentile speed when the zero speeds are excluded is equal to approximately 52 mph. As previously discussed, the zero speeds are most likely an indication the equipment malfunctioned.

Traffic Distribution by month in shown in Figure 3 for the first four months of the year, where temperatures change from very cold to variable, in Maine. April 2008 volumes appear low, however, the last four days of April volumes were not recorded, due to equipment malfunction. Projecting the traffic volumes for this period would yield an April 2008 traffic count of approximately 120,000 vehicles, which is approximately the same as the other four months, indicating little monthly fluctuation during this period in traffic volume.

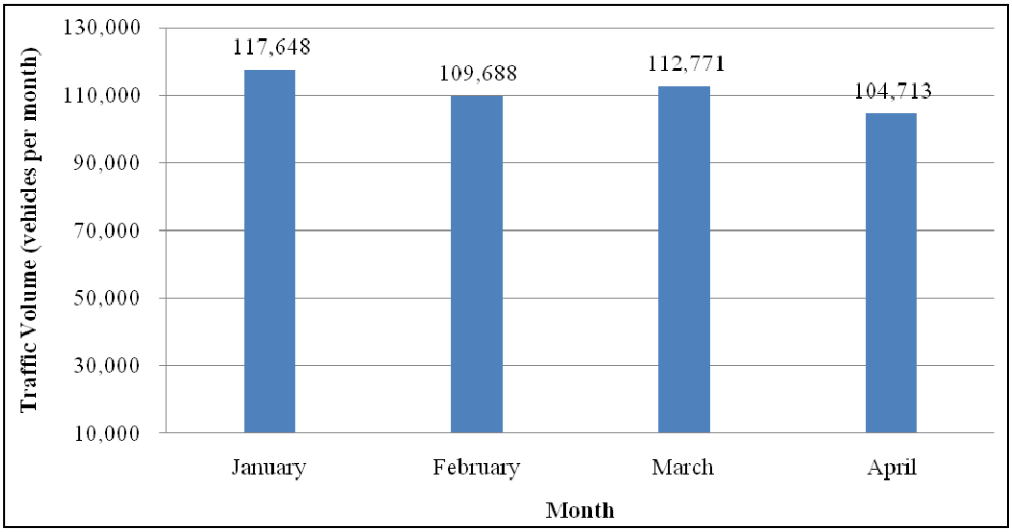


Figure 3. Monthly Variations in Traffic Volumes.

Figure 4 shows the daily fluctuation in 2008 traffic volumes from January 1, 2008 through the end of April 2008. This figure indicates a clear pattern of weekly traffic emerges. Figure 5 provides the distribution of traffic during a typical week (April 13, 2008 through April 19, 2008) of the study period. The weekly distribution of traffic is consistent in this test section, with weekend traffic volumes consistently lower then weekday traffic volumes. Weekday volumes remain consistent throughout the week with little daily fluctuation. Weekday volumes range from 4,500 to 4,800 vpd, while weekend volumes range from 2,100 to 2,500 vpd.

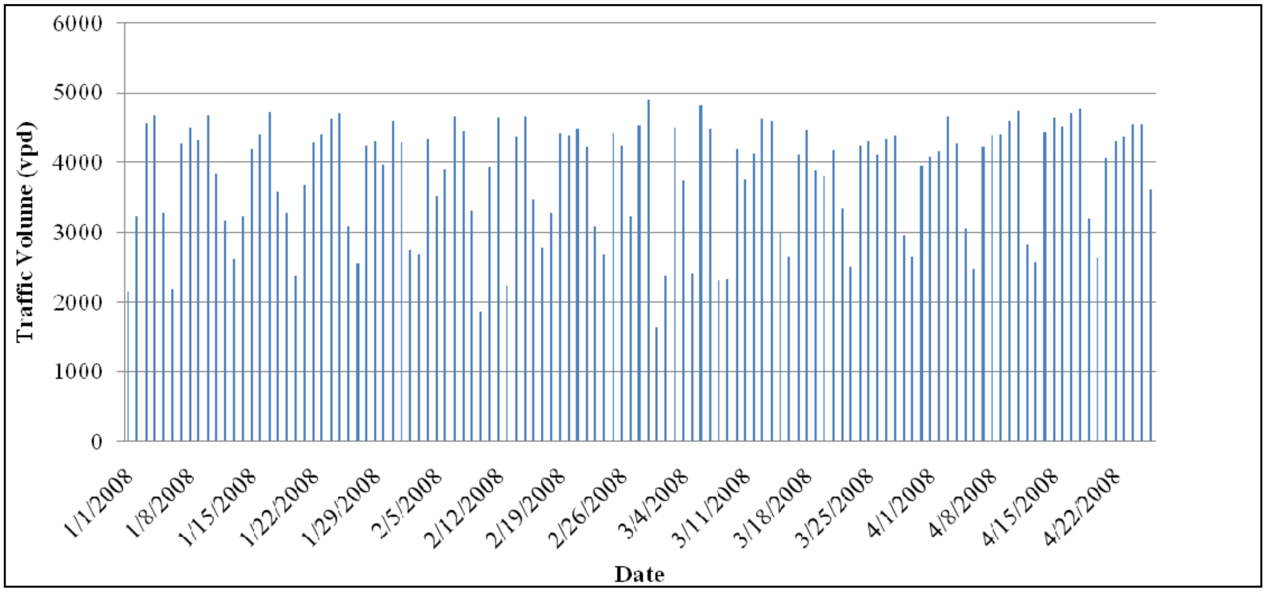


Figure 4. Daily fluctuations in 2008 traffic volumes.

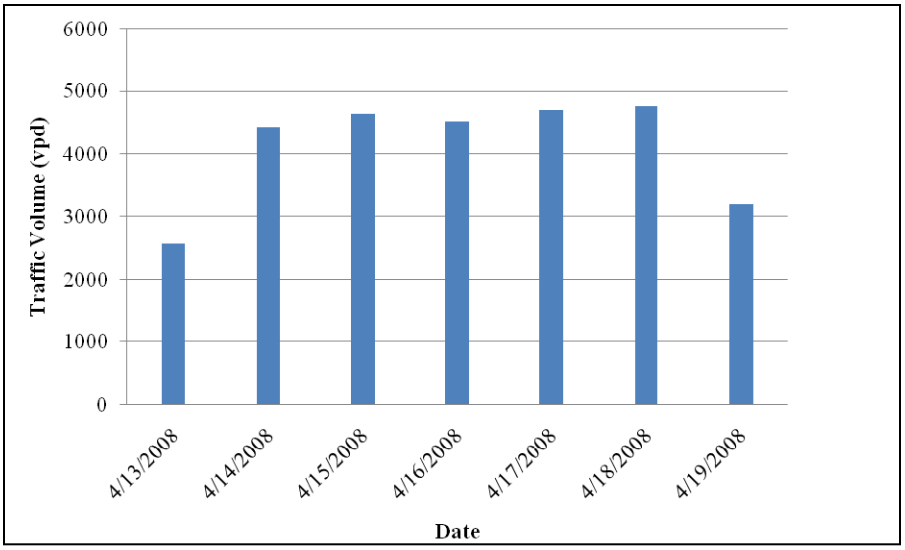


Figure 5. Distribution of traffic volumes during the peak week.

Figure 6 provides a representative plot of the hourly fluctuations of vehicle traffic for each day of the week. A clear morning and even peak hour is present during the week with a midday peak present on the weekend. Friday experiences a morning, midday and evening peak hour.

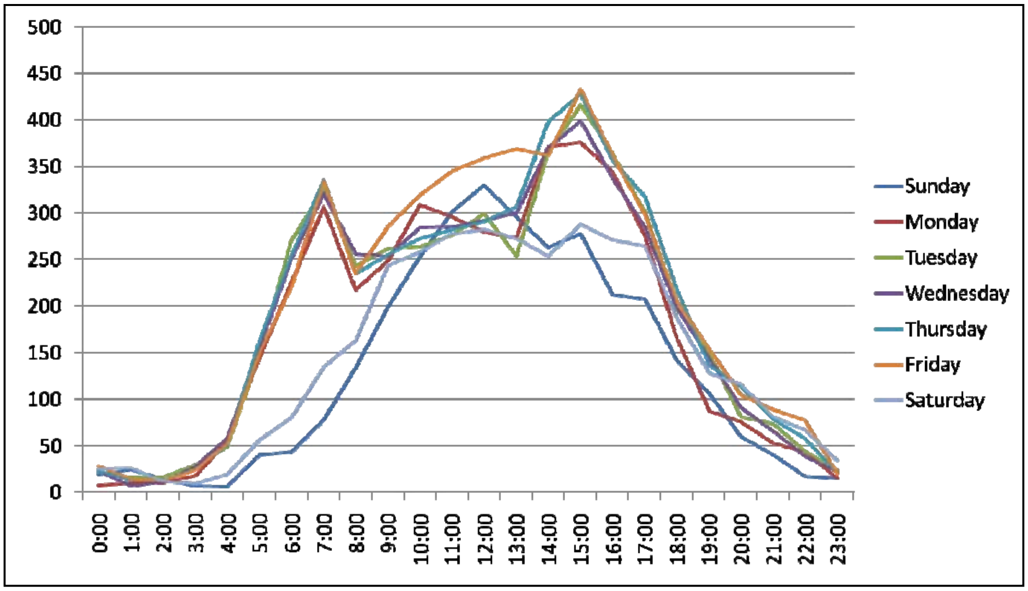
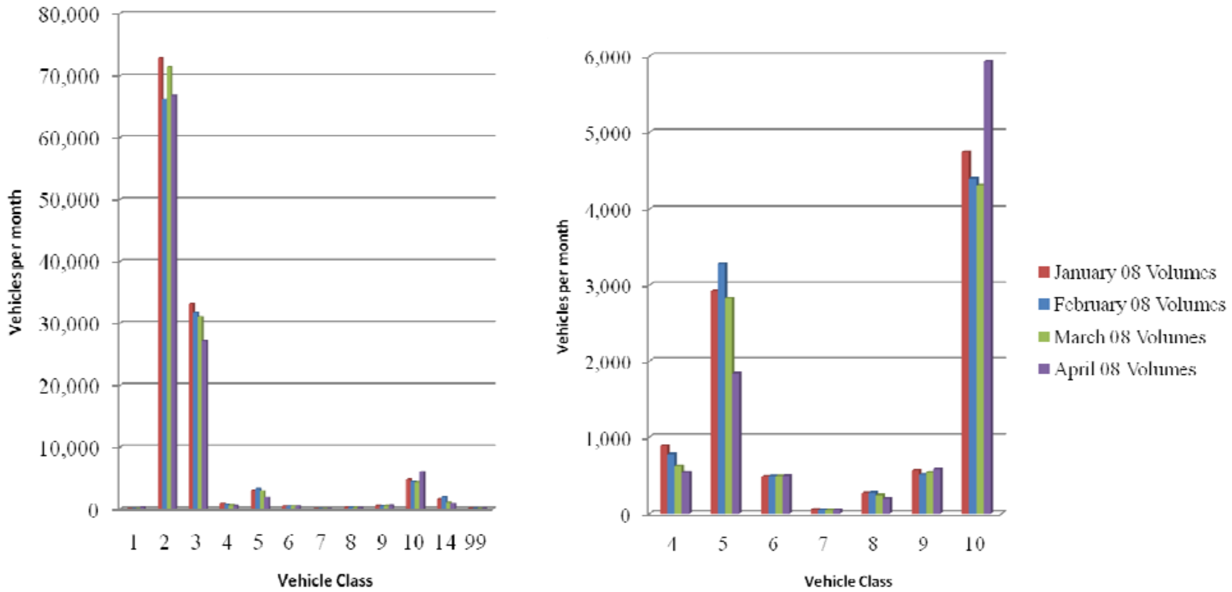


Figure 6. Distribution of traffic volumes by hour.

Figure 7a shows the distribution of vehicles by vehicle class over a four month period from January 2008 to April 2008. Class two clearly has the highest volume by vehicle class. Classes 14 and 99 are vehicles classified by the WIM as such and are shown here to indicate the number of vehicles inaccurately or unable to be classified. To more clearly demonstrate the differences between months for the larger vehicles, Figure 7b provides the same information, at a larger scale, for classes four through ten.

Axle Weight Distribution per axle analysis was conducted to identify the magnitude and frequency of loads the pavement structure is experiencing. Figure 8a through 8f show this analysis. Figures 9a and 9b provide a distribution of axle weight for the first and second axles of any vehicle that passed the WIM during the week of April 13, 2008 through April 19, 2008. All vehicles, with a few minor exceptions (e.g., unicycle), have a first and second axle and would be accounted for in Figures 8a and 9b. Consequently, Figures 8a and 9b have a weekly distribution similar to the volume distribution shown above. It should be noted, however, the lack of frequency of vehicles with axles configurations above two axles on the weekends. Furthermore, it should also be noted that as the number of axles increases, a gap develops in the recorded weights of said axle, as shown in Figures 8c through 8f. This would indicate that these larger vehicles, while traveling on this stretch of road, are obviously not always traveling fully loaded and may in fact be traveling fully loaded merely half of the time.

The minimum and maximum weights for each axle during this representative week can be found in Table 1.



(a) Classes 1-10 (b) Class 4-10 at a larger scale

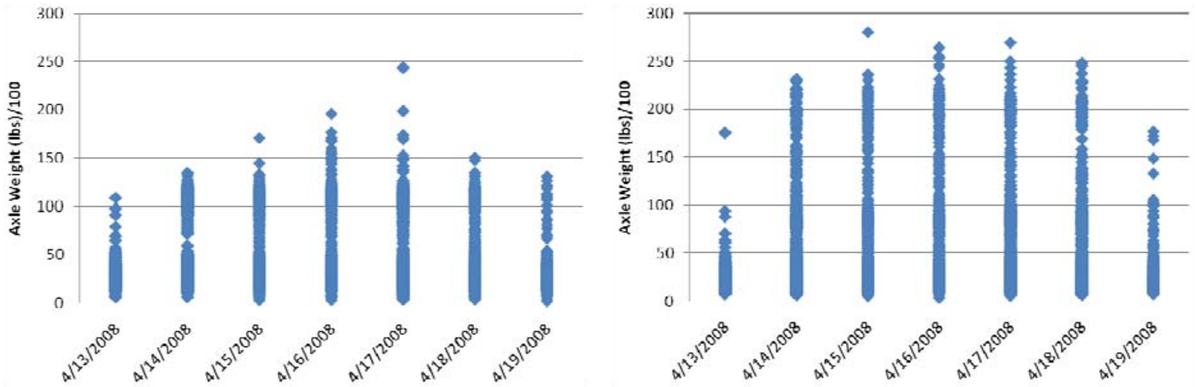
Figure 7. Distribution of traffic volumes by vehicle class.

Table 1. Axle Weight Minimum and Maximum by Axle.

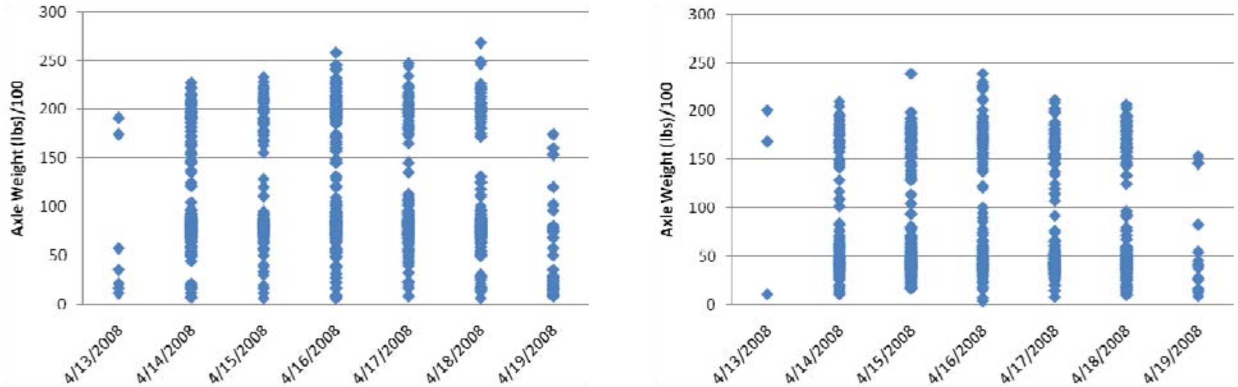
Axle Number	Weight (lbs)	
	Minimum	Maximum
1	200	34,500
2	400	28,000
3	600	26,800
4	400	23,900
5	400	22,900
6	1,100	25,600

Temperature analyses can be separated into two different categories. First, on the basis of temperature data obtained at different depths as well as air temperature, regression models relating air temperature and pavement temperatures can be determined to predict pavement temperatures at different depths on the basis of the measurable air temperature. Second, using record air temperature data, one can determined appropriate time periods for further analysis.

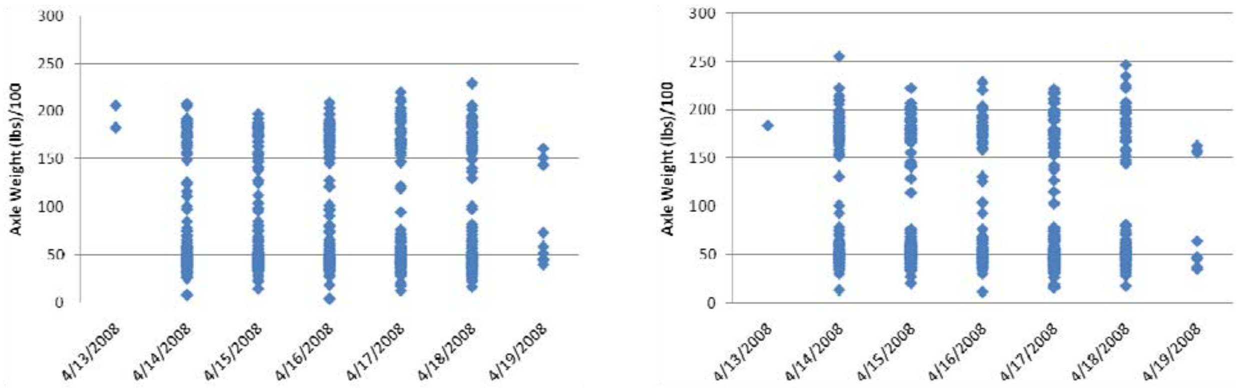
The field gathered data indicates the air and various pavement depth temperatures vary considerably. Figure 9 shows the minimum and maximum gathered temperature data from the month of April 2008 for the air temperature, a pavement depth of 203mm, and a pavement depth of 270mm.



(a) 1st Axle Weights (lbs)/100. (b) 2nd Axle Weights (lbs)/100.



(c) 3rd Axle Weights (lbs)/100. (d) 4th Axle Weights (lbs)/100.



(e) 5th Axle Weights (lbs)/100. (f) 6th Axle Weights (lbs)/100.

Figure 8. Distribution of Axle Weights by Day for a Representative Week.

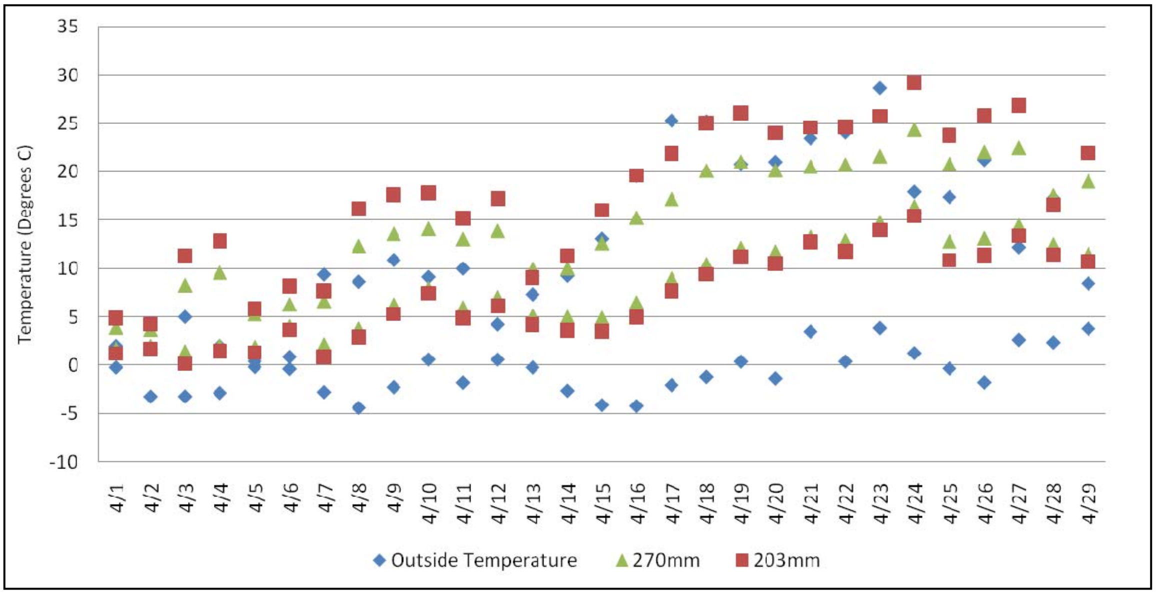


Figure 9. Field Gathered Temperatures at Various Pavement Depths and Air Temperature.

Using this gathered data and additional months of data, regression models were developed to relate air temperature to temperatures at various pavement depths where temperature data was recorded. These equations were developed for pavement depths of 35mm (T_{35}), 203mm (T_{203}), and 270mm (T_{270}). The results are as follows (all temperatures are in degree Celsius):

$$T_{35} = 1.210T_{air}+4.569 \qquad R^2=0.862$$

$$T_{203} = 0.955T_{air}+6.239 \qquad R^2=0.815$$

$$T_{270} = 0.835T_{air}+6.917 \qquad R^2=0.738$$

Using these regression models and record air temperature data, one can predict when the following temperature conditions will be experienced by the pavement and isolate data analysis periods:

1. Period of consistently below 0ºC air temperature and pavement temperature;
2. Period of fluctuating air and pavement temperature above and below 0ºC; and
3. Period of consistently above 0ºC.

The predicted pavement temperatures are presented in Figures 10 through 12. Figure 10 shows the minimum and maximum air temperature for the month of March 2008 and the predicted base pavement temperature. The base pavement temperature is predicted to be higher than the air temperature. Figure 11 shows an isolated view of the predicted pavement base temperature, indicated that as early in the year as March, the pavement is consistently above 0ºC in this region. Figure 12 superimposes the pavement temperature at a depth of 35mm. This figure verifies that more shallow depths of pavement are more susceptible to air temperature variations, while the deeper pavement temperatures are less sensitive to changes in air temperature. Figure 12 also illustrates that the shallow pavement experiences a wider variation in temperature throughout any given day than the deeper pavement and more closely mimics the air temperature.

These predicted pavement temperatures were analyzed in conjunction with gathered traffic data and the strain data to determine the effects of traffic and temperature on the pavement response, measured in strain.

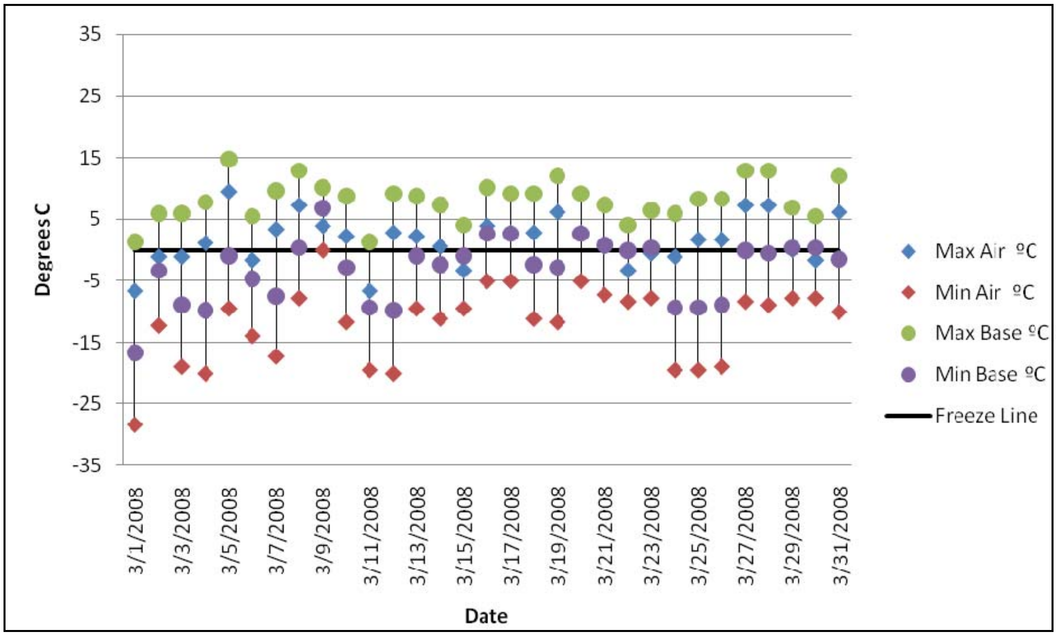


Figure 10. March Air Temperature and Predicted Base Temperature.

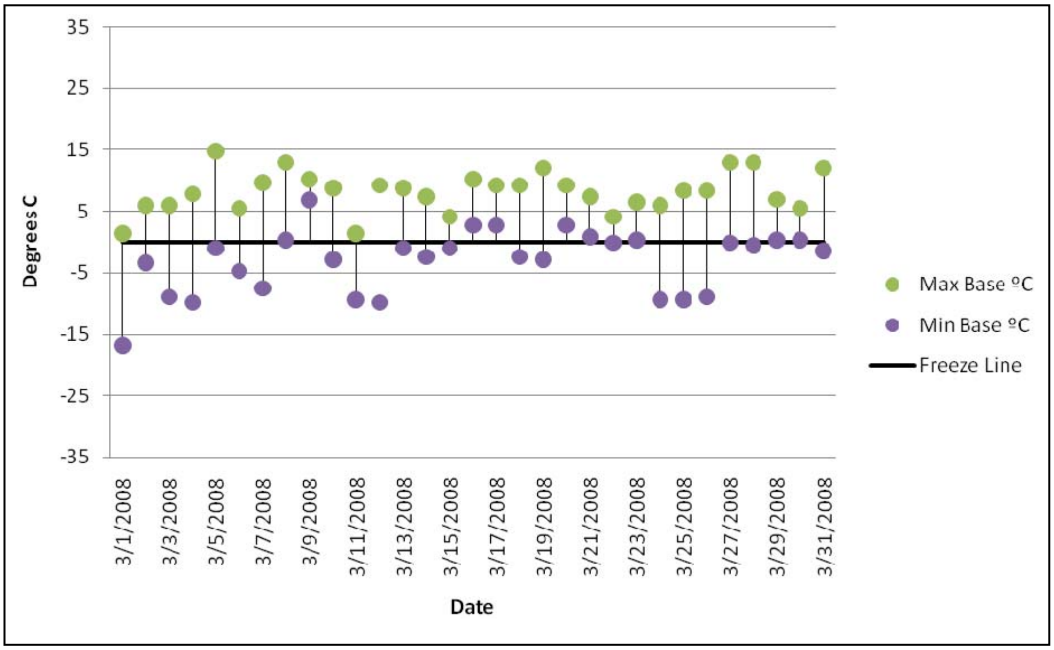


Figure 11. March Predicted Base Temperature.

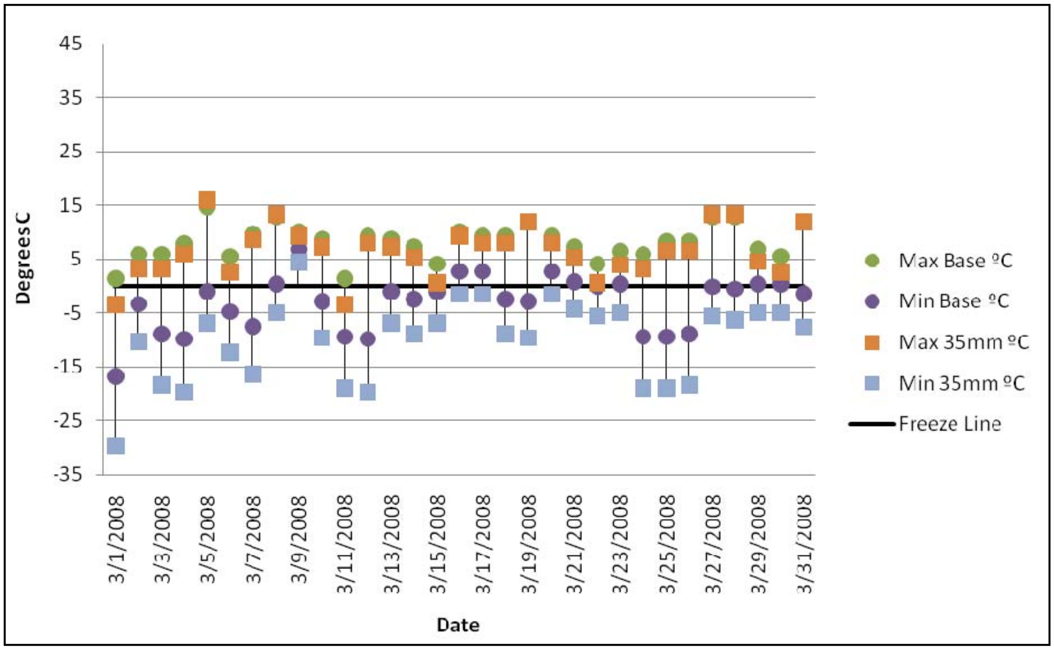
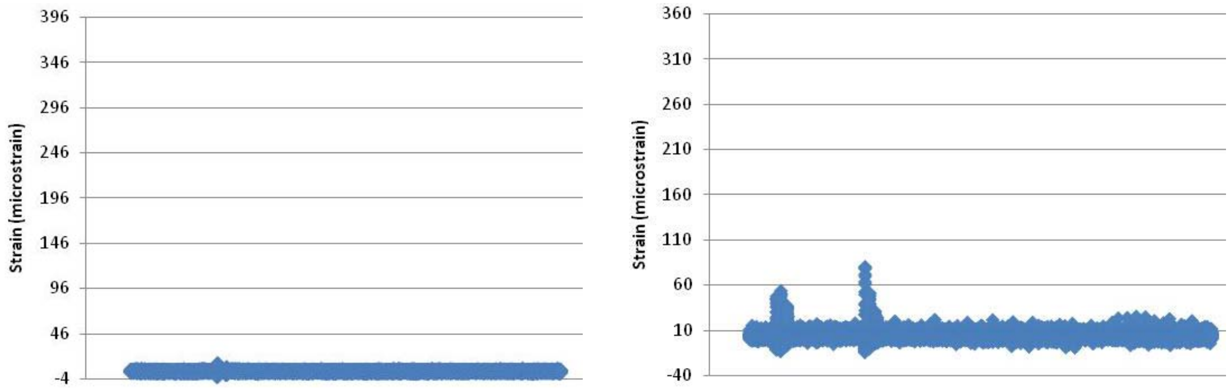


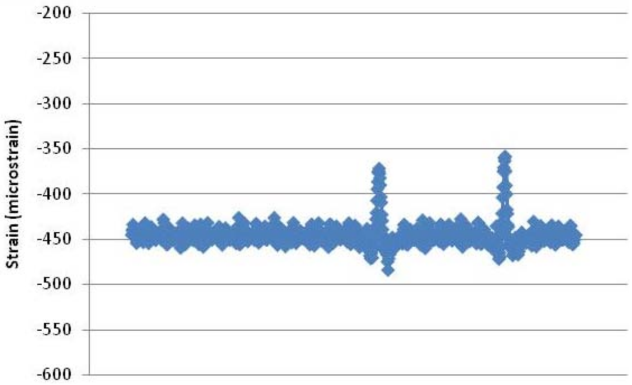
Figure 12. March Predicted Pavement Temperatures at the Base and 35mm depth.

Strain data was analyzed for a range of loads and a range of temperatures. The data were analyzed in two ways – first by splitting the loads into specific groups and noting the change in strain as a result of change in temperature, and secondly, by splitting the data into different temperature groups, and analyzing the change in strain versus change in load groups. Examples of readings for different months are shown in Figures 13a to 13c.



(a) Example Strain January 1, 2008

(b) Example Strain April 17, 2008



(c) Example Strain June 11, 2008

Figure 13. Example of strains in different months.

A review of the data from the plots shows that an increase in temperature will cause an increase in strain of 10 to 165 microstrain for the Class 10 (maximum strain) load group, and the strain increases with an increase in the temperature. The relationship between temperature and strain can be modeled (Figure 14) as follows:

$$\varepsilon=8.0234e^{0.943T} \qquad R^2 = 0.93$$

Where:
ε= Strain (microstrain)
T = Temperature (°C)

This method can be used reliably to predict the change in strain with a change in temperature of the asphalt base, at the location of the tensile strain.

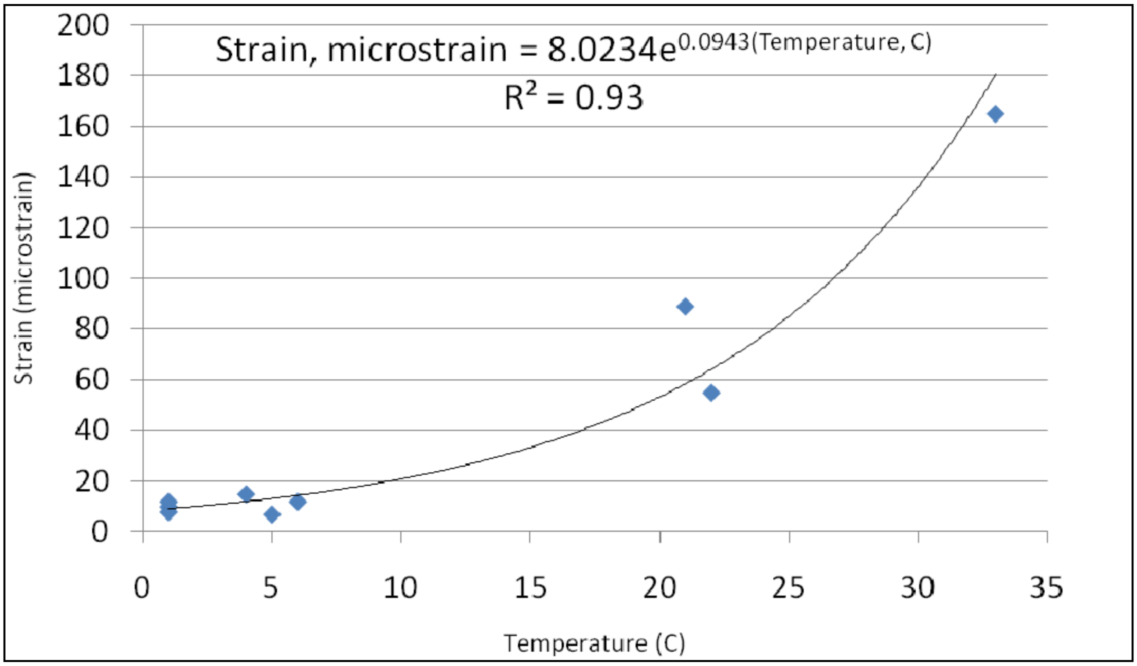


Figure 14. Relation of change in strain to change in temperature.

Step 4: Determine affect of temperature on a representative pavement structure.
The Maine data consists of a variety of loads, traveling at different speeds and at different temperatures. Ideally, a set of different loads moving at similar speeds at each of a range of different temperatures would be available to observe the affect of weight and temperature on strain. When such data is not available, these methods can be adopted to utilize the data in the best possible way.

Using the pavement strain prediction model developed during Step 3 and a repetitions to failure (Nf) model previously developed for this Maine region (Mallick 2005) shown below, one can predict the pavement strain (ε) with the Step 3 equation and then predict the pavement repitiations to failure (Nf) with this equation. The results are shown in figure 15.

$$Nf = 8.0x10^{13}\varepsilon^{-3.561} \qquad R^2 = 0.8393$$

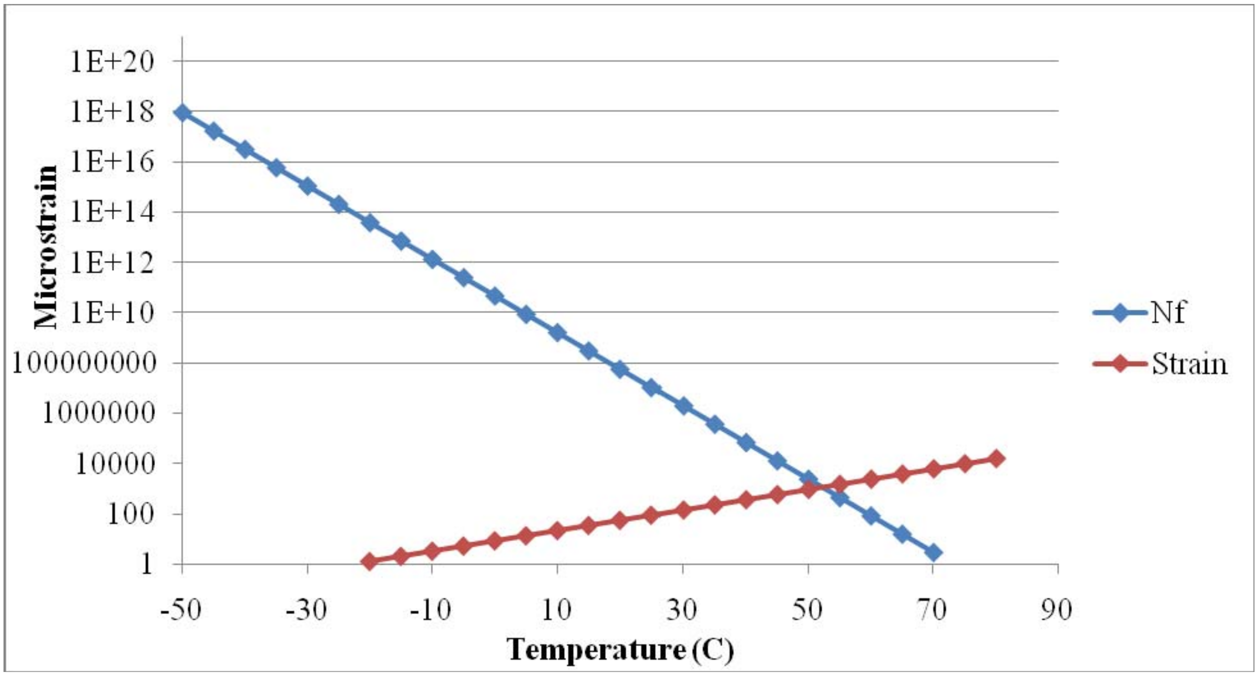


Figure 15. Relation of change in temperature to pavement life (Nf).

Step 5: Determine acceptable pavement strain and impose restrictions.
Each region must determine an acceptable level of strain (ε) or repetitions or failure (Nf) to impose load restrictions. The generally accepted endurance limit of an asphalt pavement is strain in the range of 80-100 microstrain. Using the relationships with temperature developed in Step 4 (Figure 15) and considering 80 microstrain as the endurance limit for an asphalt pavement, a percent reduction in pavement life can be calculate for an increase in temperature (Figure 16) for any one vehicle. The relationship shown in figure 16 is for a class 10 vehicle driving on the Guilford, ME test section. Damage to the pavement will occur at any temperature, relationships such as these (Figures 15 & 16) can be used to determine an acceptable level of damage to establish allowable load limits based on temperature. Upon determining the acceptable limits, the restrictions should be imposed when the strain (or repetitions to failure) as a consequence of the base temperature, is above acceptable levels. Measuring the base temperature is not desirable for every mile of every road in a given region, therefore, one should use the relationship developed in Step 3 to predict base temperature based on easily measured air temperature.

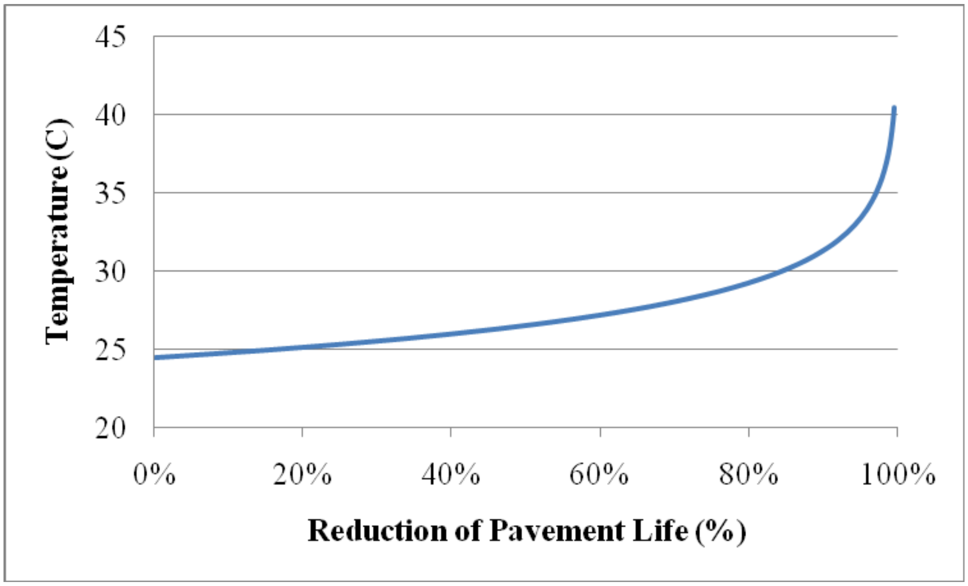


Figure 16. Percent Reduction in Pavement Life for Identical Traffic due to Temperature Increase.

CONCLUSION

Appreciable change in strain is change in pavement life. Monitoring the temperature at the base and using that to limit traffic loads or impose restrictions will extend the life of Asphalt pavements.

These restrictions are being discussed with regard to strain in pavement due to change in stiffness of the asphalt, however the asphalt strain also depends on the stiffness of the base layer which could vary significantly because of freezing and thawing, especially if the base contains a lot of moisture. In that case, the strain (deflection) in the asphalt layer could be determined using a Falling Weight Deflectometer or a deflectometer inserted through three to six inch holes in the pavement. Upon obtain the deflection measurements, the same approach can be used for the load restrictions.

The use of this approach will grant regions the ability to manage their assets with greater confidence, through every season of the year and maximize the life of asphalt pavements. These benefits far outweigh the cost of the data collection and analysis. The 2008 Maine region observations showed that strains in the January to March period are minor, and well below those in April-May time period, which are approaching the endurance strain limit, finally exceeding the endurance limit in June. This approach will allow MDOT to continue to monitor their assets, absent of additional data collection.

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REFERENCES

Mallick, Rajib B., Bhattacharjee, Sudip "*An Evaluation Of Performance And Life Cycle Cost Of Hot Mix Asphalt (HMA)Pavements Of Different Thickness*" Worcester Polytechnic Institute, November, 2005.

Mallick, Rajib B. "*Analysis of Pavement Response Data and Use of Nondestructive Testing for Improving Pavement Design and Adoption of Mechanistic-Empirical Pavement Design Procedure Using the Gilford Route 15 Instrumented Pavement Test Section: First Annual Report*" Researchers: Professor Dana Humphrey, University of Maine, Lauren Swett, University of Maine, Sean O' Brien, Worcester Polytechnic Institute, Rajib B. Mallick, Worcester Polytechnic Institute, August 4, 2006

National Oceanic and Atmospheric Administration, http://www.noaa.gov/, (accessed August 2008)