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MaineDOT

Transportation Research Division

Technical Report 08-1

Mechanistic Approach to Determine Spring Load Restrictions in Maine

March, 2008

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Introduction

Maine is in a region of the United States that experiences freezing and thawing of the roadway system during the winter season. At the beginning of the season the roadway and granular base materials begin to freeze from the top down. Frost penetration is dependent on temperature and type of granular base and subgrade materials. Frost depth can range from a depth of about 30 inches in the southern portion of the state to 60 inches or more in the north. As temperatures begin to rise above 32° F the roadway begins to thaw from the top down and to a lesser extent from the bottom up. At this time the base and sub base materials are saturated with water which reduces the load carrying properties of the roadway.

In order to prevent damage to the roadway during thaw periods the Maine Department of Transportation (MaineDOT) and municipalities can restrict heavy vehicles (gross weight over 23000 pounds) on certain State and State Aid Highways from November 15 to June 1. Vehicles with a gross weight of 23000 pounds or less, emergency and maintenance vehicles, and vehicles transporting perishable goods are exempt. Certain vehicles that are over 23000 pounds when loaded can apply for an exemption certificate.

Weight restrictions are posted based on experienced opinion or when water is observed pumping through cracks in the roadway. Removal is based on experienced opinion. Duration of weight restrictions can be between four and eight weeks.

This research will be using pavement deflections and frost gauges to determine if MaineDOT is placing and removing weight restrictions at the proper time. In addition, this research will also investigate the use of Freezing and Thawing Index formulas developed by other Transportation Departments to determine if weight restrictions can be placed based on ambient temperature.

Problem Statement

Weight restrictions are placed and removed based on experience and visual signs such as water pumping up through cracks. This method can lead to posting weight restrictions too late when the top down thaw is at a depth when heavy loads can damage the roadway. Removal of weight restrictions can also subject the roadway to weight damage if the posting is removed too early.

Another issue that has been getting attention is that many trucking companies have been arguing that the Department enforces weight restrictions too long and that many roadways are capable of supporting heavy loads long before weight restrictions are lifted.

To improve the timing and better define the method of applying weight restrictions, the use of ambient temperatures and analytical methods developed by other State Transportation Departments will be investigated. Frost gauges imbedded in the roadway and pavement deflections will be utilized to verify accuracy of the results.

Research Approach

Eight test sites were selected around central Maine to monitor pavement deflections and a frost gauge was installed on four of the eight sites to measure frost depth and rate of thaw. It was important to select sites that have experienced frost movement during spring thaw and that the roadway runs north and south for maximum sunlight exposure to accurately monitor top down thaw measurements. Maintenance personnel were interviewed to identify areas where frost movement occurs during spring thaw. North/south roadways were selected because most State Aid roads in Maine are located in heavily forested areas - that combined with the low angle of the sun tends to shade roads that run east/west which will slow progression of top down thaw. Figure 1 contains a test site location map and Table 1 contains information about each test site.

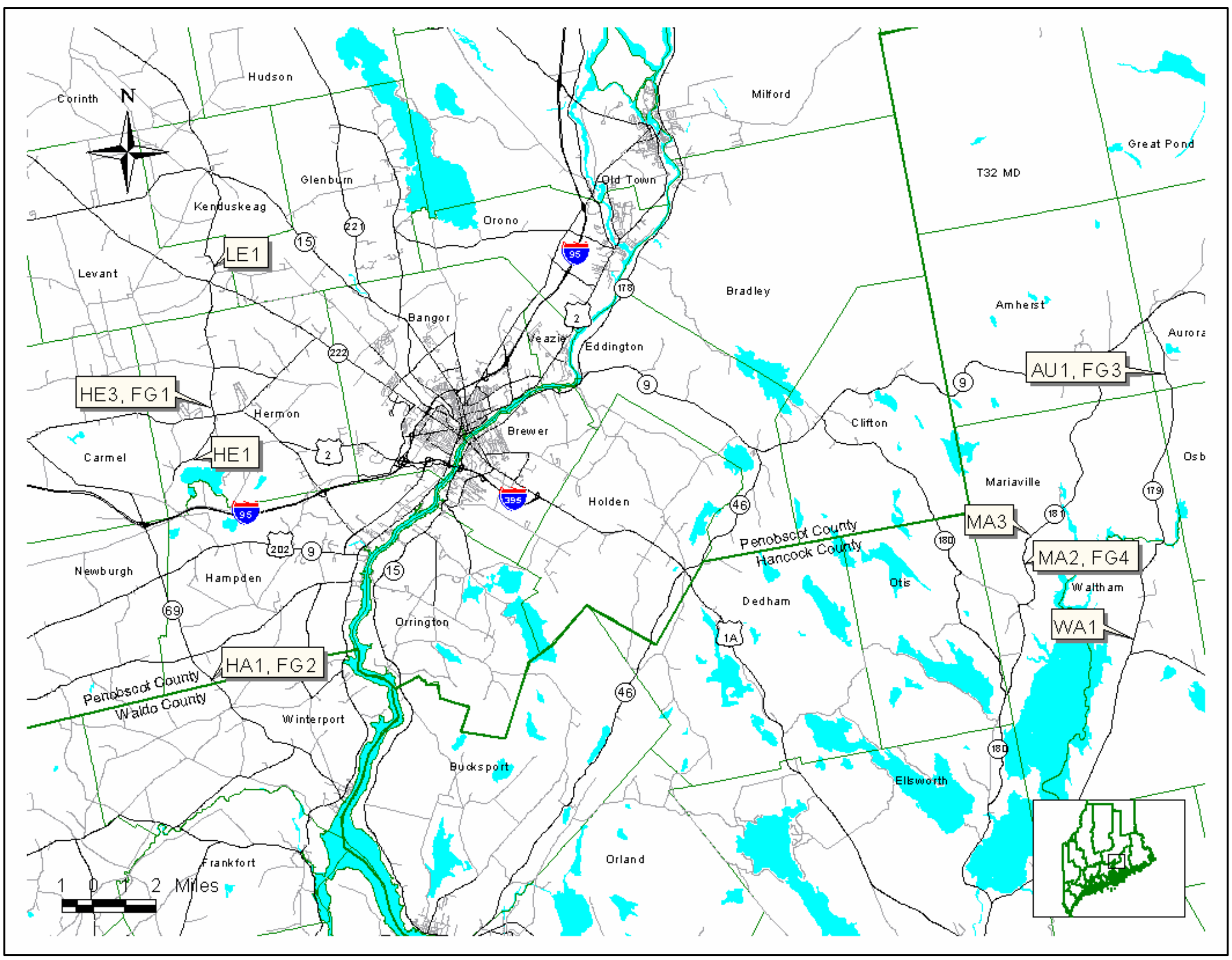

Figure 1: Test Site Location Map

Table 1: Test Site Information

Town	Route	Section ID#	Frost Gauge ID#
Aurora	179	AU1	FG3
Hampden	69	HA1	FG2
Hermon	Newburg Road	HE1	
Hermon	Wing Road	HE3	FG1
Levant	Kenduskeag Road	LE1	
Mariaville	181	MA2	FG4
Mariaville	181	MA3	
Waltham	179	WA1	

An attempt was made to select sites with dissimilar aggregate sub base soil classifications. Subsurface soil samples were collected and tested for water content, grain size, classification in accordance with AASHTO Classification System M-145-40, and Frost Susceptibility Rating based on Maine DOT and Corps of Engineers Classification Systems which ranges from Class 0 (non-frost susceptible) to Class IV (highly frost susceptible). Table 2 contains soil analysis test results and classifications for every soil layer at each test site.

The aggregate base layer which is from just under the pavement to a depth of roughly two feet has a low water content of between 4.1 and 8.8 percent and a low amount of fines with between 8.6 and 22.5 percent passing the No. 200 screen. Soil classifications are similar with a rating of A-1-a in Aurora and A-1-b for the remaining sites. Frost susceptibility ratings are low with a rating of 0 for the Aurora and Mariaville test site and II for the remaining sites.

The aggregate sub base layer is a variable depth layer that is located between two feet and six feet below the surface. This layer retains the highest amount of water for all test sites except the Newburg Road in Hermon and the Mariaville (MA3) test site. Water content runs from a low of 12.3 to a high of 26.6 percent. Finer material runs from a low of 33.0 to a high of 83.1 percent passing the No. 200 screen. There are three soil classifications for this layer, Aurora and Levant are rated A-7-5, Mariaville (MA2) is rated A-2-4, and the remaining sites are rated A-4. Frost susceptibility ratings range from a low of II in Mariaville (MA2), III in Aurora, and IV for the remaining sites.

The sub grade layer is a variable depth layer that begins at a minimum depth of 2.7 feet and maximum depth of 6.0 feet below the surface and continues to 8.0 feet or more below the surface. Water content is between a low of 8.0 to a high of 24.0 percent. This layer typically has the greatest amount of fine material. Percent passing the No. 200 screen is between a low of 40.7 in Aurora to a high of 95.4 on the Newburg Road in Hermon. There are two soil classifications for this layer. A-7-5 on the Newburg Road in Hermon and Route 181 in Mariaville (MA3) and the remaining sites are classified as A-4 soils. Frost susceptibility is rated as IV for all sites with the exception of Route 181 in Mariaville (MA2) which has a rating of III.

Four test sites had a frost gauge installed to monitor depth of frost and rate of thaw. The frost gauge is a modified version of a MaineDOT design [5] which consists of an eight foot length of 0.5 inch O.D. x 0.375 inch I.D. clear flexible polyethylene tubing filled with a dark blue solution of 0.05 percent methylene blue. The methylene blue solution turns clear when frozen making it ideal for measuring depth of frost. The tube is inserted into a 1.5 inch PVC pipe which is sealed on the bottom and capped with a 3.625 inch watertight flush fill cap as displayed in Figure 2.

Table 2: Test Site Soil Classifications

Depth (feet)	Water Content	% Passing #200	Classification		
			Unified	AASHTO	Frost
		Route 179, Aurora, AU1,FG3			
0.3-2.6	5.7	10.5	SW-SM	A-1-a	0
2.6-5.2	18.6	80.2	CL	A-7-5	III
5.2-5.7	Cobble				
5.7-8.0	11.8	40.7	SC-SM	A-4	IV
8.0-10.0	11.2	37.2	SM	A-4	III
		Route 69, Hampden, HA1, FG2			
0.80-2.3	6.0	22.0	SM	A-1-b	II
2.3-6.0	26.6	63.9	CL-ML	A-4	IV
6.0-8.3	11.3	86.1	ML	A-4	IV
		Newburg Road, Hermon, HE1			
0.60-2.1	8.8	22.5	SM	A-1-b	II
2.1-3.0	13.6	76.3	CL-ML	A-4	IV
3.0-10.0	24.0	95.4	CL	A-7-5	IV
		Wing Road, Hermon, HE3, FG1			
0.60-1.9	6.6	17.9	SM	A-1-b	II
1.9-5.5	15.1	60.9	CL-ML	A-4	IV
5.5-8.2	11.7	56.3	ML	A-4	IV
8.2-10.0	6.8	35.2	SM	A-2-4	II
		Kenduskeag Road, Levant, LE1			
0.50-1.6	4.1	24.8	SM	A-1-b	II
1.6-2.7	24.7	83.1	CL	A-7-5	IV
2.7-5.3	14.7	71.2	ML	A-4	IV
5.3-7.7	7.7	33.2	SM	A-2-4	II
7.7-10.0	14.1	46.1	SM	A-4	III
		Route 181, Mariaville, MA2, FG4			
0.70-1.8	6.8	8.6	SW-SM	A-1-b	0
1.8-3.2	14.0	33.0	SC-SM	A-2-4	II
3.2-10.0	9.6	49.7	SM	A-4	III
		Route 181, Mariaville, MA3			
0.30-2.2	5.0	9.3	SW-SM	A-1-b	0
2.2-5.7	13.4	62.7	ML	A-4	IV
5.7-9.1	18.8	95.3	CL	A-7-5	IV
9.1-10.0	16.8	71.2	CL-ML	A-4	IV
		Route 179, Waltham, WA1			
0.40-2.3	6.3	20.5	SM	A-1-b	II
2.3-2.8	Cobble				
2.8-4.5	12.3	55.0	CL-ML	A-4	IV
4.5-7.0	8.0	51.8	ML	A-4	IV
7.0-10.0	6.1	37.6	SM	A-2-4	III

It’s important that the gauge is watertight to prevent water from collecting inside the pipe. If water is trapped and depth of freezing is below water level the gauge will freeze in place and render it unusable until spring thaw. It’s also important to screw three or four brass screws into the PVC bushing to anchor the frost gauge and prevent it from rotating when removing the recessed brass plug.

The gauge is installed by boring a hole in the right wheel path using a 5 inch solid stem auger. Soil samples are collected during this process. The frost gauge is inserted into the hole until the fill cap is 0.25 inch below pavement surface in order to prevent snow plow damage. Soil is placed around the frost tube to a height of 6 ±1 inches below the surface. The area around the fill cap is sealed with a quick curing cement product.

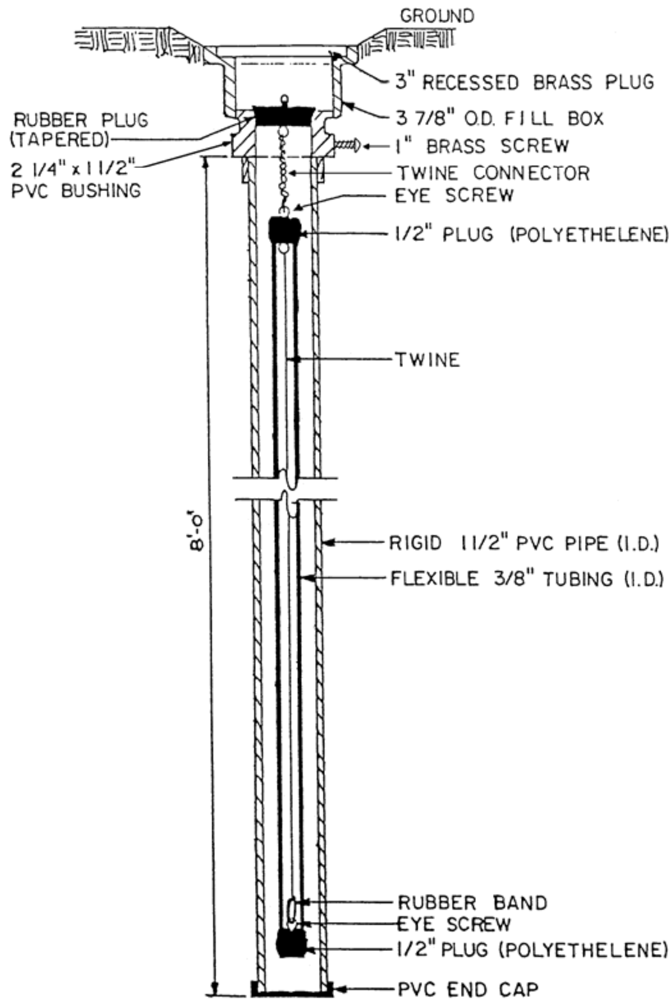

Figure 2: Frost Gauge Design (not to scale)

Depth of frost is measured by unscrewing the brass plug, withdrawing the tube and measuring the length of clear solution. Rate of top down thaw can also be measured when the fluid regains its blue color as displayed in Photo 1. Nylon twine is anchored inside the flexible tube to prevent the frozen zone from shifting inside the tube. The top 5 or 6 inches of the gauge is not capable of measuring frost depth due to the void between the roadway surface and the point where methylene blue solution begins.

Results

Frost and deflection data were collected during the winter of 2006 - 2007. Frost data from measurements in Aroostook County and the Bangor area from prior research [5] combined with historical ambient temperatures was also used in an attempt to verify frost and thaw calculations.

Manual Frost Measurements

Frost depth and thaw measurements were collected between two and three times per week. Figure 3 contains a graphical display of each measurement. Hermon, Hampden, and Aurora had very similar aggregate sub base soil types and as a result very similar freezing and thawing patterns. Sub base soil analysis at the Mariaville site contained more granular material which resulted in reduced frost penetration and earlier frost out date. Spring Load Restriction research in Minnesota [3] also reported early frost out dates for granular test sites.

Photo 1: Frost Gauge Reading on 3/21/2007. Blue dye is visible at the top and bottom of the gauge (unfrozen state). Clear section is frozen.

A secondary frost was recorded on March 19 at the Hermon and Hampden sites only. The test site in Aurora (FG3) has the greatest frost penetration and latest frost out date. Sub base soil analyses reveal that this site has the highest percentage of minus 200 material which could be contributing to the increased frost depth.

Calculated Frost Measurements

Wisconsin and Minnesota Transportation Departments have developed equations to predict rate of frost, maximum depth of frost, start of top down thaw, thaw duration, and spring load restriction duration using average daily temperatures and freezing and thawing index equations [4, 6]. Minnesota continues to adjust the formulas to better define spring load restrictions [2, 3].

Weather information from the Bangor International Airport combined with formulas developed from Minnesota's Engineering Services Department [2] were used to determine if MaineDOT can develop spring load restriction guidelines from freezing and thawing index values.

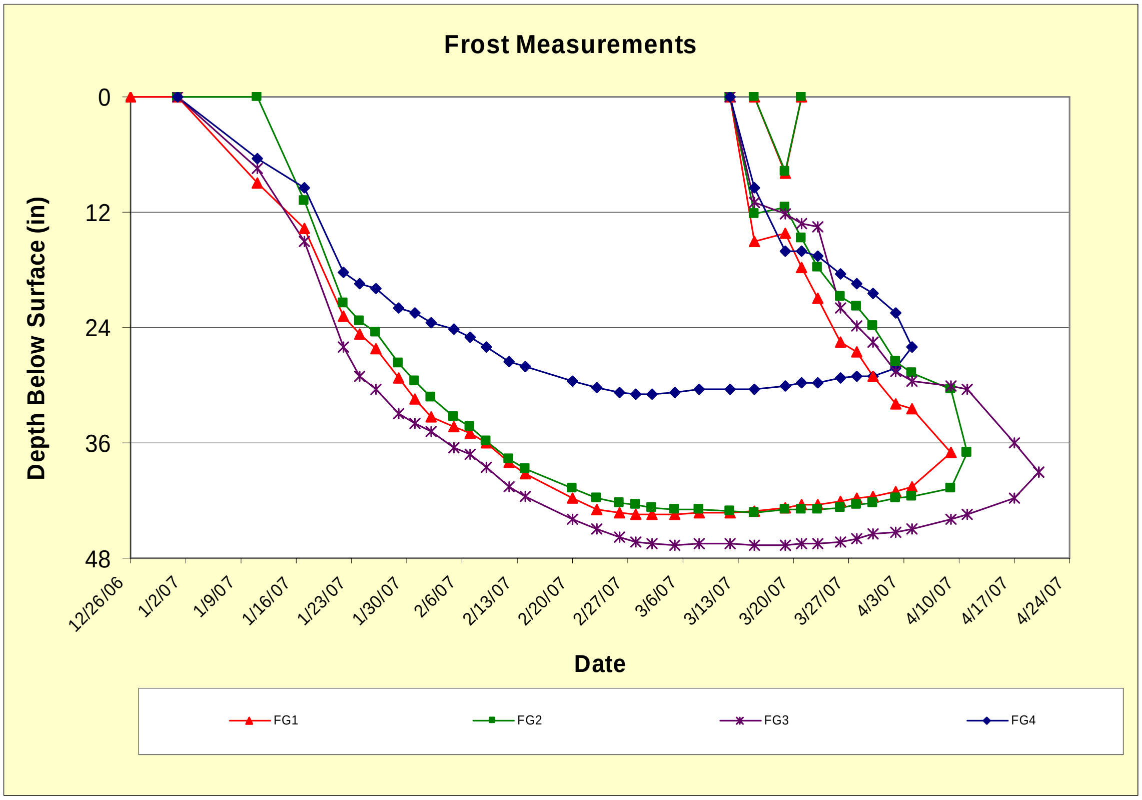

Figure 3: Frost Depth and Thaw Measurements

The cumulative freezing index is calculated using the following equation:

$$CFI = \sum_{i=1}^{n} (Daily\ Freezing\ Index)$$

$$Daily\ Freezing\ Index = \left(T_{reference} - \frac{T_{\max imum} + T_{\min imum}}{2} \right)$$

Where: CFI = cumulative freezing index calculated over a period from 1 to n days (ºC-day),
$T_{reference}$ = Reference air temperature (see Table 3) (ºC),
$T_{maximum}$ = Maximum daily air temperature (ºC), and
$T_{minimum}$ = Minimum daily air temperature (ºC).

The cumulative thawing index is calculated using the following equation:

$$CTI = \sum_{i=1}^{n} (Daily\ Thawing\ Index - 0.5 * Daily\ Freezing\ Index)$$

$$When \left(\frac{T_{\max imum} + T_{\min imum}}{2} - T_{reference} \right) > 0^{o} C,$$

$$Daily\ Thawing\ Index = \left(\frac{T_{\max imum} + T_{\min imum}}{2} - T_{reference} \right), and$$

$$Daily\ Freezing\ Index = 0^{o} C - day$$

$$When \left(\frac{T_{\max imum} + T_{\min imum}}{2} - T_{reference} \right) < 0^{o} C,$$

$$Daily\ Thawing\ Index = 0^{o} C - day, and$$

$$Daily\ Freezing\ Index = \left(0^{o} C - \frac{T_{\max imum} + T_{\min imum}}{2} \right)$$

Where: CTI = cumulative thawing index calculated over a period from 1 to n days (ºC-day),
$T_{maximum}$ = Maximum daily air temperature (ºC),
$T_{minimum}$ = Minimum daily air temperature (ºC), and
$T_{reference}$ = Reference air temperature (see Table 3) (ºC).

With the following notes:

- The above equation is valid for temperatures in degrees Celsius or Fahrenheit.
- A floating reference temperature is used to account for increased solar gain. As illustrated in Table 3, the solar gain is reflected using a freezing temperature depression of 1.5 ºC (2.7 ºF) during the first seven days of February; and thereafter, a depression of 0.5 ºC (0.9 ºF) per week.
- A refreeze factor of 0.5 is used to account for the partial phase change of water from a liquid to a semi-solid during temporary refreeze events.

The reference temperature is used to compensate for the temperature differential between the air temperature and asphalt temperature when the asphalt temperature is 32±1 ºF. In Minnesota the average daily air temperature was 30.4, 27.9, and 24.3 ºF for the months of January, February, and March respectively. This meant that the air temperature required for thawing to begin decreases from January to March due to the increase in declination of the sun at springtime. Road Weather Information System (RWIS) stations located throughout Maine collect air and pavement temperature data and can be utilized to adjust the reference temperature to fit conditions at various locations across Maine. Ideally data from the past three winter seasons would be necessary to accurately adjust the reference temperature. Unfortunately archived RWIS data is only available from November 2007 to present.

Table 3: CFI and CTI Reference Temperature

Date	Reference Temperature (ºF)	Reference Temperature (ºC)
January 1 – January 31	32	0
February 1 – February 7	29.3	-1.5
February 8 – February 14	28.4	-2
February 15 – February 21	27.5	-2.5
February 22 – February 29	26.6	-3
March 1 – March 7	25.7	-3.5
March 8 – March 14	24.8	-4
March 15 – March 21	23.9	-4.5
March 22 – March 28	23	-5
March 29 – April 4	22.1	-5.5
April 5 – April 11	21.2	-6
April 12 – April 18	20.3	-6.5
April 19 – April 25	19.4	-7
April 26 – May 2	18.5	-7.5
May 3 – May 9	17.6	-8
May 10 – May 16	16.7	-8.5
May 17 – May 23	15.8	-9
May 24 – May 30	14.9	-9.5
June 1 – December 31	32	0

The following equations from studies conducted at the University of Waterloo, Canada [1] were used to calculate depth of frost and rate of thaw;

$$FD = -5.537\sqrt{CFI}$$

Where: FD = Frost depth below the pavement's surface, cm, and
CFI = Cumulative freezing index (in ºC-days).

$$TD = -5.537\sqrt{CTI}$$

Where: TD = Thaw depth below the pavement's surface, cm, and
CTI = Cumulative thawing index (in ºC-days).

When combining the calculated and measured frost depth as displayed in Figure 4, the calculated frost depth aligns very well with the measured frost depth at the Hermon, Hampden, and Aurora test sites. The Mariaville test site does not match very well due to the granular properties of the sub base soil inhibiting frost penetration.

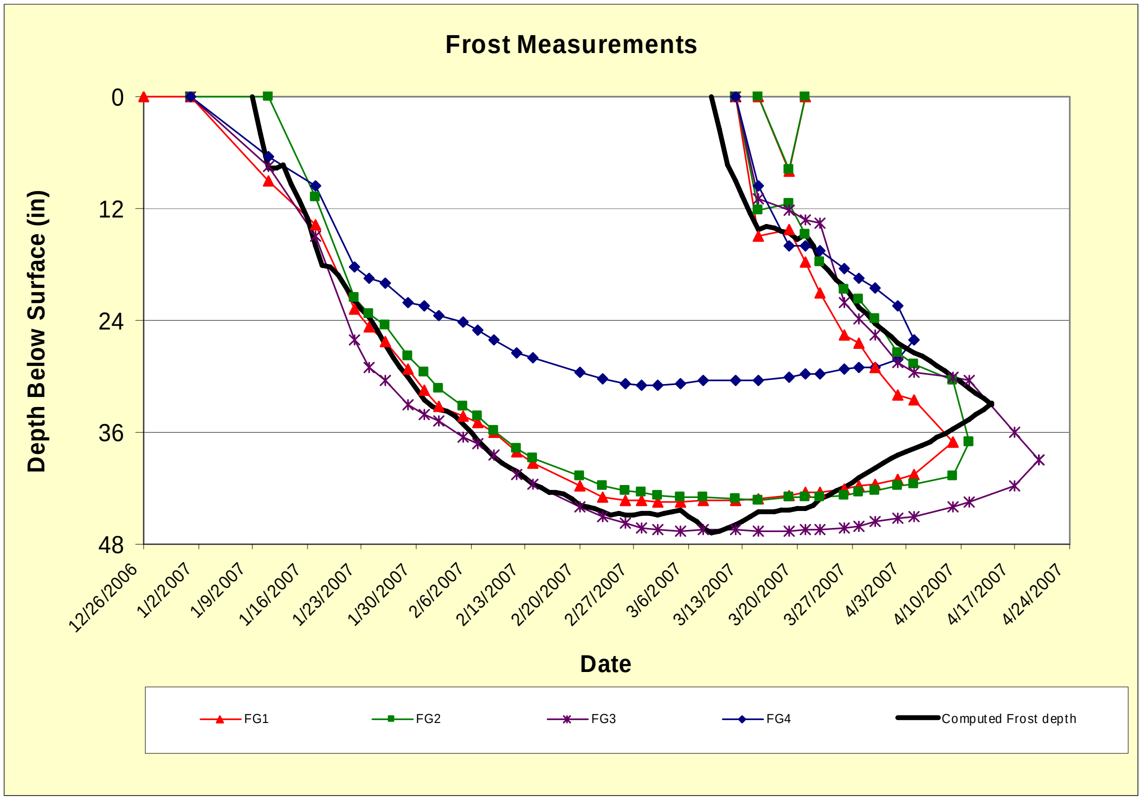

Figure 4: Calculated Frost Depth

Calculated freeze begins on January 9, 2007. Measured freeze begins on January 11, 2007. As mentioned earlier the top 5 or 6 inches of the gauge is not capable of measuring frost therefore measured frost must have started prior to January 11th.

Calculated thaw started on March 10, 2007. Measured thaw began on March 15, 2007. The beginning of measured thaw is also affected by frost gauge limitations and could have started prior to March 15th.

Adjustments to the reference temperature in Table 3 should align the calculated frost depth more closely the to measured frost depth.

Appendix A contains a worksheet for calculating daily freeze and thaw index, cumulative freeze and thaw index, plus measured freeze and thaw depths.

Pavement Deflections

A Falling Weight Deflectometer (FWD) was utilized to measure structural conditions of each test site during spring thaw. The FWD is equipped with a 12 inch diameter load plate and seven geophones. The distance of each geophone from the center of the load plate is 0, 12, 18, 24, 36, 48, and 60 inches. Pavement deflections are measured in mils when a 9000 pound weight is dropped on the load plate. The weight is dropped on the load plate three times to produce an average deflection for each geophone.

Each test site has five test points that are 25 feet apart. Deflections are measured at each test point and all five test points are averaged to produce one set of deflections for each test site for each test date. FWD data is analyzed using DARWin 3.1 developed by the American Association of State Highway and Transportation Officials. FWD data, frost depth measurements, and spring load restriction dates for the four sites that have a frost gauge are displayed in Appendix B. The remaining four test sites were monitored for abnormal deflections during spring thaw. Deflection results from these sites were similar to the test sites that had frost gauges and similar soil types. This study will concentrate on the four sites with frost gauges.

Base line FWD data was collected on September 25 and 26, 2006 when the test sites are typically in the best condition structurally and during spring thaw between March and May 2007.

FWD data is processed as Sum of Deflection which is the sum of all seven geophones, Structural Number which is a number generated from DARWin that represents the structural capacity of the test site - the greater the Structural Number the greater the strength, and Subgrade Modulus which is the subgrade resilient modulus expressed in pounds per square inch.

As expected the Sum of Deflections is low when the roadway is frozen and increases at a steady rate as the frost thaws from top down. Values stop increasing within two days of the point where frost is no longer visible in the frost tube. Values fluctuate after that period possibly due to rainfall affecting the already saturated condition of the roadway. This value does not appear to be a good indicator of when the SLR should be removed.

Structural Number values are very high when the roadway is frozen and decreases at a steady rate while frost is thawing. The value begins to increase again within two days of the point when frost is out. From that point on the Structural Number continues to increase as the roadway begins to drain with a few instances of slightly decreased values possibly due to rainfall.

The Subgrade Resilient Modulus followed a similar pattern as the Structural Number with a steady decrease in values until the frost went out then an increase in values. Values increased at a steady rate after April 30th to a point where the modulus surpassed the September base value on May 9th.

Pavement deflections are a very good real time indicator of when the roadway is frozen, when frost has left the roadway and when the roadway is structurally sound but can not be used to predict when each of these conditions will exist.

Spring Load Restrictions

Spring load restrictions in Maine are placed based on visual observations such as water pumping from cracks or roadway frost deformation. When using this method it's possible to post the road after the critical period when heavy loads can damage the roadway. Experience and visual cues such as diminished water runoff in ditches are used to remove spring load restrictions. This method can result in a road being closed to heavy loads much longer than necessary.

Spring load restrictions for MnDOT begin when the CTI exceeds 25 F degree-days (14 C degree-days). A three day weather forecast is used to determine when the CTI will reach 25 F degree-days (14 C degree-days) and the extended forecast is used to determine if the CTI will be well above 25 F degree-days (14 C degree-days). The three day forecast is used to ensure that the roadway is posted before critical thawing begins and to give the public a 3-day notice as to when the road will be posted.

The MaineDOT CTI surpassed 25 F degree-days on March 12, 2007. Measured top down thaw on all four frost tubes had not started or was less than 6 inches on that date. Calculated thaw depth on March 12th was at 9.1 inches. The first measured thaw was on March 15th and registered from a low of 9.5 inches to a high of 15 inches below surface. Madden [5] suggests load restrictions should be placed when the roadway has thawed to a depth of 9.5 inches below the bottom of the pavement which equates to a thaw depth in inches from the surface of 16.7 in Hermon, 19.1 in Hampden, 13.1 in Aurora, and 17.9 in Mariaville. This may not be a realistic target to gauge SLR because the Structural Number is at or lower than the September base value when frost has reached this depth and heavy loads may begin to inflict damage to the roadways at this point.

SLR was posted in Hermon on March 15th, three days after the calculated SLR date, when top down thaw was at a depth of 15 inches.

Hampden was posted on March 10th, two days before calculated SLR. Frost had not begun to thaw at that point or was less than 6 inches in depth.

Aurora was posted on March 10th, two days prior to calculated SLR. Top down thaw had not started or was less than 6 inches in depth.

Mariaville was posted on March 9th which was three days before the calculated SLR date. Top down thaw was less than 6 inches in depth or had not started at this time.

It appears that roadways in the Bangor area should be posting when the CTI exceeds 25 F degree-days. This indicator can be predicted using 7 day weather forecasts giving trucking industries ample time to adjust operations.

Minnesota [3] has developed the following formula to determine how long it will take for the frost to go out based on maximum daily freezing index and maximum frost depth;

$$D = 0.15 + 0.10FI + 19.1FD - 12090 * \frac{FD}{FI}$$

Where: D = Duration of thaw period in days

FI = Maximum CTI, ºC-Days

FD = Maximum frost depth, m, or $\frac{FD_{max}}{100}$

Calculations result in a maximum frost depth of 46.8 inches and a thaw duration of 38 days. If using the calculated thaw begin date of March 10th and thaw duration of 38 days the frost would be out on April 17th which is very close to the actual frost out date of April 20th in Aurora but later than the frost out dates of April 9th and 11th in Hermon and Hampden.

Minnesota uses a combination of (1) measured and forecast daily air temperatures (cumulative thawing index), (2) cumulative spring precipitation, (3) accumulated fall precipitation measured during preceding year, and (4) maximum cumulative freezing index from the preceding winter freeze period to determine when to remove SLR. They have determined that the minimum duration of SLR should be 4 weeks while the maximum duration will not exceed 8 weeks.

Minnesota also allows Winter Load Increases of up to 10 percent when the CFI exceeds 280 F degree-days (156 C degree-days) and the extended CFI continues to exceed 280 F degree-days (156 C degree-days). Winter Load Increases are removed when top down thaw has started and SLR dates have been predicted. These indicators can be determined using 7 day weather forecasts.

Historical Frost data

To determine the effectiveness of using formulas to predict frost penetration, historical ambient temperatures were used to compare calculated frost depth to measured frost depth data collected by Madden [5] in the Bangor area and northeastern Maine in the Houlton area during the winter of 1988-1989. Unfortunately the measured frost depth data is not complete but it does give an indication of overall frost depth and thaw.

Houlton Area

Frost measurements were collected in northeastern Maine on Route 1, Settlement Road, and B Road in Houlton and on Route 212 in Merrill. Ambient temperatures were recorded from the Houlton International Airport.

Figure 5 contains calculated and manual frost readings from the sites in northeastern Maine. Manual bottom of frost readings are similar for the Route 1 and B Road sites in Houlton but vary widely for the Settlement Road and Route 212 sites. The measured rate of thaw is somewhat similar for all four sites.

The frost and thaw depth calculations do not match the manual readings very well. Calculated rate of thaw is much slower than measured thaw and depth of frost is greater than measured depth in most locations. Although there is no frost out dates for the manual readings it's apparent that the calculated frost out date is a minimum of three weeks later than the actual date would be. Adjustments to the reference temperature (Table 3) should bring the calculated frost and thaw line closer to the measured line.

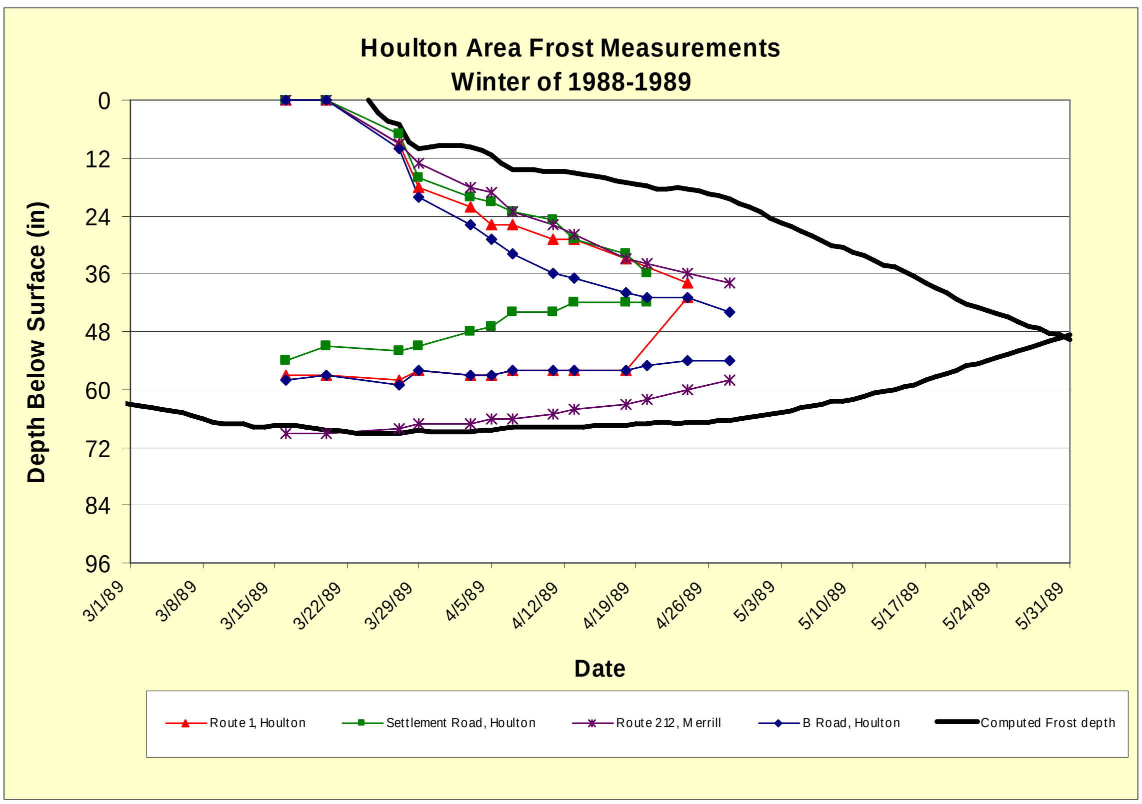

Figure 5: Historical Frost Measurements in the Houlton Area.

Bangor Area

Frost measurements near the Bangor area were collected in the towns of Glenburn, Corinth, Garland, and Dexter. Bangor International Airport temperatures were used to calculate the frost and thaw depths. Figure 6 contains a summary of the results.

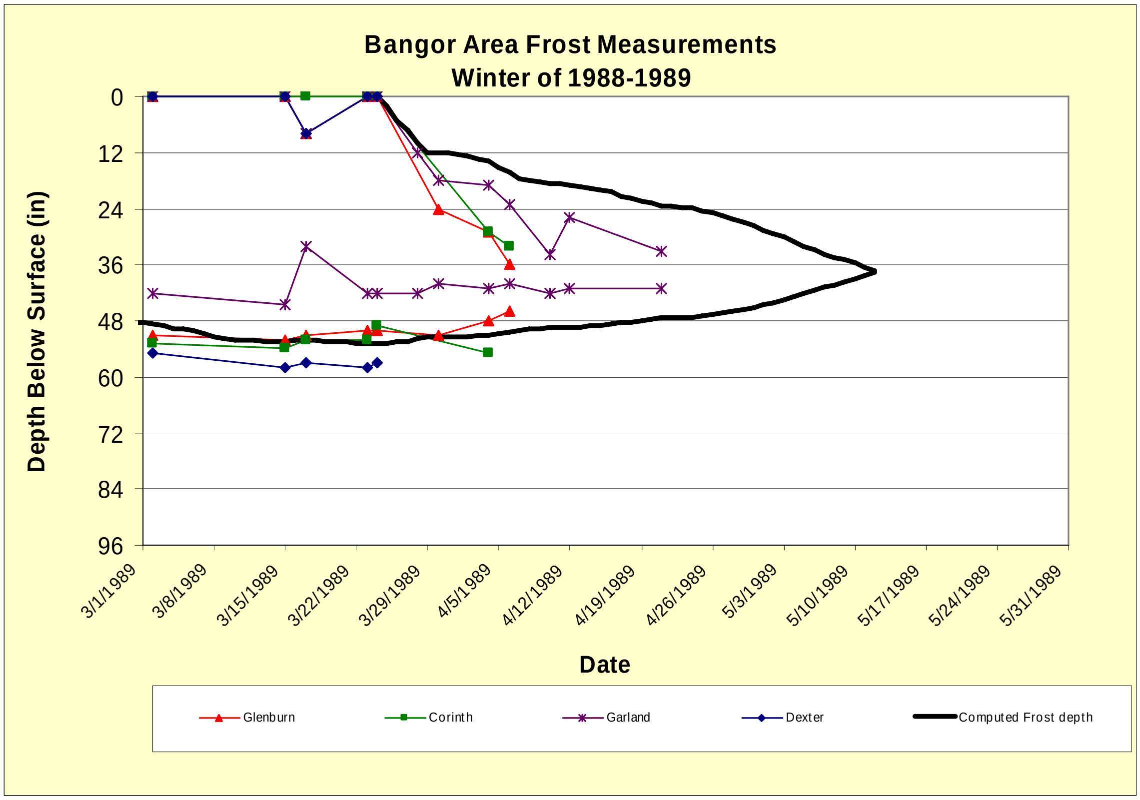

Figure 6: Historical Frost Measurements in the Bangor Area.

Frost depth measurements are similar for the Glenburn, Corinth, and Dexter sites. Frost did not penetrate as deep at the Garland site. Measured rate of thaw is very similar for Glenburn, Corinth, and Garland. The Dexter site had only one top down thaw reading on March 13th.

Calculated depth of frost follows the measured rate much better than the Houlton area did. Calculated rate of thaw is slower than measured rate. Refinements to the reference table should improve the calculated results.

Conclusions

There is no doubt that roads which are not built to state standards cannot support heavy truck loads while frost is thawing from the top down. Visual cues are used to post and remove Spring Load Restrictions. This method may result in restricting loads too early, to the aggravation of the trucking industry, or too late resulting in damage to the road. Or the restriction is posted much longer that the trucking industry feels is necessary. It would be cost beneficial to the Department and trucking industries if the roads were posted at the proper time to reduce damage and give 3 to 7 days notification as to when the roads will be posted.

In an effort to standardize the posting and removal of Spring Load Restrictions and give the trucking industry ample time to plan for road postings the MaineDOT researched using real time and forecast ambient temperatures combined with formulas developed from other government agencies to determine when to post SLR’s.

Research shows that using ambient temperatures with adjustments to the formulas can be used to effectively predict when to post and remove SLR’s. Formula adjustments can be determined with the use of pavement temperature data from Road Weather Information Systems located across Maine.

An automated website could be developed to predict where and when SLR postings will be in effect. Trucking industries can then review the website and make plans to avoid these roadways prior to road postings.

Recommendations

The following recommendations should be followed to accurately develop formulas to determine when to place and remove SLR’s:

- Divide the state into zones that represent areas of changing frost development.
- Use RWIS pavement and air temperature data to determine reference temperatures for each zone.
- Install frost gauges in each zone to aid in the development of SLR Guidelines.
- Use National Weather Service ambient temperature data to determine when to place and remove SLR’s in remote areas with no RWIS stations.
- Develop an automated website that will predict SLR post and removal dates for each zone.
- SLR should be posted when the Cumulative Freezing Index exceeds 25 F degree-days (14 C degree-days).
- SLR removal dates can be fixed time spans or determined from frost depth calculations.
- Winter Load Increases can be allowed when the CFI exceeds 280 F degree-days (156 C degree-days) and the extended CFI continues to exceed 280 F degree-days (156 C degree-days).
- Winter Load Increases should be removed when top down thaw has started.

References

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APPENDIX A

Date	Average Air Temperature (°F)	Daily Freezing Index (°F - days)	Cumulative Freezing Index (°F - days)	Calculated Frost Depth (inches)	Measured Frost Depth (inches)				Daily Thawing Index (°F - days)	Cumulative Thawing Index (°F - days)	Calculated Thaw Depth (inches)	Measured Top Down Thaw Depth (inches)			
					FG1	FG2	FG3	FG4				FG1	FG2	FG3	FG4
1/1/2007	24.6	7.4			0.0	0.0	0.0	0.0							
1/2/2007	34.4	-2.4													
1/3/2007	31.6	0.4													
1/4/2007	33.9	-1.9													
1/5/2007	36.8	-4.8													
1/6/2007	49.9	-17.9													
1/7/2007	41.8	-9.8													
1/8/2007	34.5	-2.5													
1/9/2007	36	-4.0		0.0											
1/10/2007	26.1	5.9	5.9	4.0											
1/11/2007	15.4	16.6	22.5	7.7	9.0	0.0	7.5	6.5							
1/12/2007	32.5	-0.5	22.0	7.6											
1/13/2007	34.2	-2.2	19.8	7.2											
1/14/2007	17.8	14.2	34.0	9.5											
1/15/2007	18.7	13.3	47.3	11.2											
1/16/2007	15.7	16.3	63.6	13.0											
1/17/2007	-1.1	33.1	96.7	16.0	13.8	10.8	15.0	9.5							
1/18/2007	5.2	26.8	123.5	18.1											
1/19/2007	28.3	3.7	127.2	18.3											
1/20/2007	21.4	10.6	137.8	19.1											
1/21/2007	9.9	22.1	159.9	20.6											
1/22/2007	9.7	22.3	182.2	22.0	22.8	21.5	26.0	18.3							
1/23/2007	16.5	15.5	197.7	22.9											
1/24/2007	16.7	15.3	213.0	23.7	24.8	23.3	29.0	19.5							
1/25/2007	8.7	23.3	236.3	25.0											
1/26/2007	-0.9	32.9	269.2	26.7	26.3	24.5	30.5	20.0							
1/27/2007	3.7	28.3	297.5	28.0											
1/28/2007	9.5	22.5	320.0	29.1											
1/29/2007	8.6	23.4	343.4	30.1	29.3	27.8	33.0	22.0							
1/30/2007	4.9	27.1	370.5	31.3											
1/31/2007	3.6	28.4	398.9	32.5	31.5	29.5	34.0	22.5							

Table A-1: Calculated and Measured Frost Depth Readings.

Date	Average Air Temperature (ºF)	Daily Freezing Index (ºF - days)	Cumulative Freezing Index (ºF - days)	Calculated Frost Depth (inches)	Measured Frost Depth (inches)				Daily Thawing Index (ºF - days)	Cumulative Thawing Index (ºF - days)	Calculated Thaw Depth (inches)	Measured Top Down Thaw Depth (inches)			
					FG1	FG2	FG3	FG4				FG1	FG2	FG3	FG4
2/1/2007	12.5	16.8	415.7	33.1											
2/2/2007	16.8	12.5	428.2	33.6	33.3	31.3	34.8	23.5							
2/3/2007	27.7	1.6	429.8	33.7											
2/4/2007	14.3	15.0	444.8	34.3											
2/5/2007	5.2	24.1	468.9	35.2	34.3	33.3	36.5	24.3							
2/6/2007	5.3	24.0	492.9	36.1											
2/7/2007	6.1	23.2	516.1	36.9	35.0	34.3	37.3	25.0							
2/8/2007	3.3	25.1	541.2	37.8											
2/9/2007	5.1	23.3	564.5	38.6	36.0	35.8	38.5	26.0							
2/10/2007	9.1	19.3	583.8	39.3											
2/11/2007	11.6	16.8	600.6	39.8											
2/12/2007	16.2	12.2	612.8	40.2	38.0	37.8	40.5	27.5							
2/13/2007	6.2	22.2	635.0	40.9											
2/14/2007	9.6	18.8	653.8	41.5	39.3	38.8	41.5	28.0							
2/15/2007	18.3	9.2	663.0	41.8											
2/16/2007	9.1	18.4	681.4	42.4											
2/17/2007	24.2	3.3	684.7	42.5											
2/18/2007	21.6	5.9	690.6	42.7											
2/19/2007	13	14.5	705.1	43.1											
2/20/2007	7.2	20.3	725.4	43.8	41.8	40.8	44.0	29.5							
2/21/2007	22	5.5	730.9	43.9											
2/22/2007	16.1	10.5	741.4	44.2											
2/23/2007	16.3	10.3	751.7	44.5	43.0	41.8	45.0	30.3							
2/24/2007	18.4	8.2	759.9	44.8											
2/25/2007	27.1	-0.5	759.4	44.8											
2/26/2007	23.3	3.3	762.7	44.9	43.3	42.3	45.8	30.8							
2/27/2007	25.4	1.2	763.9	44.9											
2/28/2007	33.6	-7.0	756.9	44.7	43.4	42.5	46.3	31.0							

Table A-2: Calculated and Measured Frost Depth Readings (cont.).

Date	Average Air Temperature (ºF)	Daily Freezing Index (ºF - days)	Cumulative Freezing Index (ºF - days)	Calculated Frost Depth (inches)	Measured Frost Depth (inches)				Daily Thawing Index (ºF - days)	Cumulative Thawing Index (ºF - days)	Calculated Thaw Depth (inches)	Measured Top Down Thaw Depth (inches)			
					FG1	FG2	FG3	FG4				FG1	FG2	FG3	FG4
3/1/2007	24.7	1.0	757.9	44.7					-3.7						
3/2/2007	23.8	1.9	759.8	44.8	43.5	42.8	46.5	31.0	-4.1						
3/3/2007	29.6	-3.9	755.9	44.7					3.9						
3/4/2007	33.2	-7.5	748.4	44.4					7.5						
3/5/2007	27.6	-1.9	746.5	44.4	43.5	43.0	46.6	30.8	1.9						
3/6/2007	5.8	19.9	766.4	45.0					-13.1						
3/7/2007	2.8	22.9	789.3	45.6					-14.6						
3/8/2007	0.3	24.5	813.8	46.3	43.3	43.0	46.5	30.5	-15.9						
3/9/2007	8.4	16.4	830.2	46.8					-11.8		0.0				
3/10/2007	29.4	-4.6	825.6	46.7					4.6	4.6	3.5				
3/11/2007	40.2	-15.4	810.2	46.2					15.4	20.0	7.3				
3/12/2007	35.8	-11.0	799.2	45.9	43.3	43.1	46.5	30.4	11.0	31.0	9.1	0.0	0.0	0.0	0.0
3/13/2007	36.4	-11.6	787.6	45.6					11.6	42.6	10.6				
3/14/2007	41.8	-17.0	770.6	45.1					17.0	59.6	12.5				
3/15/2007	42	-18.1	752.5	44.6	43.1 / 0	43.3 / 0	46.6	30.4	18.1	77.7	14.3	15.0	12.3	11.0	9.5
3/16/2007	22.8	1.1	753.6	44.6					-4.6	73.1	13.9				
3/17/2007	26.7	-2.8	750.8	44.5					2.8	75.9	14.2				
3/18/2007	27.2	-3.3	747.5	44.4					3.3	79.2	14.5				
3/19/2007	26.3	-2.4	745.1	44.3	42.8 / 8.0	43.0 / 7.8	46.6	30.0	2.4	81.6	14.7	14.3	11.5	12.3	16.0
3/20/2007	30.8	-6.9	738.2	44.1					6.9	88.5	15.3				
3/21/2007	21.3	2.6	740.8	44.2	42.5 / 0	43.0 / 0	46.5	29.8	-5.4	83.2	14.8	17.8	14.8	13.3	16.0
3/22/2007	36	-13.0	727.8	43.8					13.0	96.2	15.9				
3/23/2007	45.9	-22.9	704.9	43.1	42.5	42.9	46.5	29.8	22.9	119.1	17.7	21.0	17.8	13.5	16.5
3/24/2007	35.8	-12.8	692.1	42.7					12.8	131.9	18.7				
3/25/2007	37.5	-14.5	677.6	42.3					14.5	146.4	19.7				
3/26/2007	34.4	-11.4	666.2	41.9	42.0	42.8	46.3	29.3	11.4	157.8	20.4	25.5	20.8	22.0	18.5
3/27/2007	40.5	-17.5	648.7	41.4					17.5	175.3	21.5				
3/28/2007	41.2	-18.2	630.5	40.8	41.8	42.5	46.0	29.0	18.2	193.5	22.6	26.5	21.8	23.8	19.5
3/29/2007	35.3	-13.2	617.3	40.4					13.2	206.7	23.3				
3/30/2007	38.8	-16.7	600.6	39.8	41.5	42.3	45.5	29.0	16.7	223.4	24.3	29.0	23.8	25.5	20.5
3/31/2007	36.7	-14.6	586.0	39.3					14.6	238.0	25.1				

Table A-3: Calculated and Measured Frost Depth Readings (cont.).

Date	Average Air Temperature (ºF)	Daily Freezing Index (ºF - days)	Cumulative Freezing Index (ºF - days)	Calculated Frost Depth (inches)	Measured Frost Depth (inches)				Daily Thawing Index (ºF - days)	Cumulative Thawing Index (ºF - days)	Calculated Thaw Depth (inches)	Measured Top Down Thaw Depth (inches)			
					FG1	FG2	FG3	FG4				FG1	FG2	FG3	FG4
4/1/2007	36.1	-14.0	572.0	38.9					14.0	252.0	25.8				
4/2/2007	36	-13.9	558.1	38.4	41.0	41.8	45.3	28.3	13.9	265.9	26.5	32.0	27.5	28.5	22.5
4/3/2007	32.4	-10.3	547.8	38.0					10.3	276.2	27.0				
4/4/2007	30.4	-8.3	539.5	37.7	40.5	41.6	45.0	Out	8.3	284.5	27.4	32.5	28.8	29.5	Out
4/5/2007	30.9	-9.7	529.8	37.4					9.7	294.2	27.9				
4/6/2007	33	-11.8	518.0	37.0					11.8	306.0	28.4				
4/7/2007	32.4	-11.2	506.8	36.6					11.2	317.2	28.9				
4/8/2007	31	-9.8	497.0	36.2					9.8	327.0	29.4				
4/9/2007	35.5	-14.3	482.7	35.7	Out	40.8	44.0		14.3	341.3	30.0	Out	30.5	30.0	
4/10/2007	35.7	-14.5	468.2	35.2					14.5	355.8	30.6				
4/11/2007	35.6	-14.4	453.8	34.6		Out	43.5		14.4	370.2	31.2		Out	30.5	
4/12/2007	33.5	-13.2	440.6	34.1					13.2	383.4	31.8				
4/13/2007	34	-13.7	426.9	33.6					13.7	397.1	32.4				
4/14/2007	38	-17.7	409.2	32.9					17.7	414.8	33.1				
4/15/2007	34.2	-13.9	395.3	32.3					13.9	428.7	33.6				
4/16/2007	36.7	-16.4	378.9	31.6					16.4	445.1	34.3				
4/17/2007	36.7	-16.4	362.5	30.9			41.8		16.4	461.5	34.9			36.0	
4/18/2007	40.4	-20.1	342.4	30.1					20.1	481.6	35.6				
4/19/2007	45.3	-25.9	316.5	28.9					25.9	507.5	36.6				
4/20/2007	50.6	-31.2	285.3	27.5			Out		31.2	538.7	37.7			Out	
4/21/2007	53.1	-33.7	251.6						33.7	572.4					
4/22/2007	47.2	-27.8	223.8						27.8	600.2					
4/23/2007	57.9	-38.5	185.3						38.5	638.7					
4/24/2007	58.5	-39.1	146.2						39.1	677.8					
4/25/2007	46.3	-26.9	119.3						26.9	704.7					
4/26/2007	47.8	-29.3	90.0						29.3	734.0					
4/27/2007	45.1	-26.6	63.4						26.6	760.6					
4/28/2007	44.5	-26.0	37.4						26.0	786.6					
4/29/2007	46	-27.5	9.9						27.5	814.1					
4/30/2007	42.8	-24.3	-14.4						24.3	838.4					

Table A-4: Calculated and Measured Frost Depth Readings (cont.).

APPENDIX B

Location	Date	F W D Analysis			Frost Depth (inches)			Spring Load Restriction	
		Sum of Deflection (mils)	Structural Number	Subgrade Modulus (psi)	Bottom		Top		
					1st	2nd		Posted	Calculated
Wing Road, Hermon, HE3, FG1	9/25/2006	74.85	3.18	4,590	-	-	-	-	-
	3/12/2007								On
	3/14/2007	25.95	3.92	16,982	43.13		15.00		
	3/15/2007							On	
	3/19/2007	36.96	3.52	10,184	42.75	8.0	14.25		
	3/21/2007	41.64	3.43	8,105	42.50		17.75		
	3/23/2007	54.54	3.28	5,333	42.50		21.00		
	3/26/2007	78.18	3	3,776	42.00		25.50		
	3/28/2007	75.97	3.07	3,688	41.75		26.50		
	3/30/2007	87.02	2.93	3,336	41.50		29.00		
	4/2/2007	107.41	2.78	2,913	41.00		32.00		
	4/4/2007	114.67	2.76	2,848	40.50		32.50		
	4/9/2007	99	2.91	3,288	Out				
	4/11/2007	106.47	2.86	3,057	Out				
	4/19/2007								Off
	4/20/2007	89.59	3.06	4,325	Out				
	4/23/2007	78.23	3.29	4,702	Out				
	4/26/2007	77.19	3.26	4,787	Out				
	4/30/2007	90.12	3.05	3,272	Out				
	5/2/2007	82.49	3.1	4,411	Out			Off	
	5/4/2007	80.73	3.18	4,540	Out				
	5/9/2007	68.84	3.51	5,599	Out				
Route 69, Hampden, HA1, FG2	9/25/2006	68.87	3.87	5,195	-	-	-	-	-
	3/10/2007							On	
	3/12/2007								On
	3/14/2007	19.31	6.22	41,786	43.25		12.25		
	3/19/2007	25.12	4.81	19,341	43.00	7.8	11.50		
	3/21/2007	25.58	4.59	16,394	43.00		14.75		
	3/23/2007	37.93	4.73	18,360	42.88		17.75		
	3/26/2007	53.16	3.77	8,982	42.75		20.75		
	3/28/2007	53.1	3.74	8,356	42.50		21.75		
	3/30/2007	64.01	3.53	6,990	42.25		23.75		
	4/2/2007	73.42	3.44	5,965	41.75		27.50		
	4/4/2007	80.5	3.31	5,655	41.61		28.75		
	4/9/2007	78.46	3.34	4,677	40.75		30.50		
	4/11/2007	80.99	3.4	4,455	Out				
	4/19/2007								Off
	4/20/2007	79.59	3.6	5,014	Out				
	4/23/2007	78.92	3.79	5,591	Out				
	4/26/2007	71.87	3.8	5,751	Out			Off	
	4/30/2007	79.71	3.57	4,960	Out				
	5/2/2007	71.89	3.73	5,641	Out				
	5/4/2007	67.11	3.92	5,822	Out				
	5/9/2007	59.34	4.16	6,867	Out				

Location	Date	F W D Analysis			Frost Depth (inches)			Spring Load Restriction	
		Sum of Deflection (mils)	Structural Number	Subgrade Modulus (psi)	Bottom		Top	Posted	Calculated
					1st	2nd			
Route 179, Aurora, AU1, FG3	9/26/2006	83.17	4.17	3,806	-	-	-	-	-
	3/10/2007							On	
	3/12/2007								On
	3/14/2007	18.82	6.88	39,209	46.63		11.00		
	3/19/2007	21.48	6.15	15,273	46.63		12.25		
	3/21/2007	27.02	6.03	11,333	46.50		13.25		
	3/23/2007	35.42	5.38	18,760	46.50		13.50		
	3/26/2007	50.4	4.5	10,448	46.25		22.00		
	3/28/2007	58.21	4.26	8,474	46.00		23.75		
	3/30/2007	57.91	4.23	7,500	45.50		25.50		
	4/2/2007	67.19	4.04	6,478	45.25		28.50		
	4/4/2007	68.73	4.07	5,865	45.00		29.50		
	4/9/2007	78.41	3.83	4,920	44.00		30.00		
	4/11/2007	80.92	3.85	4,431	43.50		30.50		
	4/19/2007								Off
	4/20/2007	98.43	3.84	3,305	Out				
	4/23/2007	81.27	4.06	3,817	Out				
	4/26/2007	79.93	4.07	3,890	Out				
	4/27/2007							Off	
	4/30/2007	86.48	4	3,888	Out				
	5/2/2007	78.85	4.02	3,855	Out				
	5/4/2007	79.01	4.09	4,109	Out				
	5/9/2007	70.63	4.54	4,239	Out				
Route 181, Mariaville, MA2, FG4	9/26/2006	49.7	3.39	6,103	-	-	-	-	-
	3/9/2007							On	
	3/12/2007								On
	3/14/2007	31.81	3.75	10,264	30.38		9.50		
	3/19/2007	39.57	3.65	6,884	30.00		16.00		
	3/21/2007	41.65	3.57	7,279	29.75		16.00		
	3/23/2007	61.01	3.05	4,682	29.75		16.50		
	3/26/2007	87.36	2.8	3,329	29.25		18.50		
	3/28/2007	98.95	2.68	3,585	29.00		19.50		
	3/30/2007	113.65	2.6	2,685	29.00		20.50		
	4/2/2007	115.46	2.65	2,664	28.25		22.50		
	4/4/2007	98.53	2.77	2,816	Out				
	4/9/2007	83.8	2.76	3,762	Out				
	4/11/2007	98.41	2.65	3,360	Out				
	4/19/2007								Off
	4/20/2007	96.46	2.77	3,485	Out				
	4/23/2007	80.93	2.9	4,489	Out				
	4/26/2007	71.57	2.99	5,017	Out				
	4/27/2007							Off	
	4/30/2007	84.12	2.88	3,660	Out				
	5/2/2007	75.12	2.95	4,635	Out				
	5/4/2007	74.33	3	4,976	Out				
	5/9/2007	67.98	3.2	6,555	Out				