Final Report 2000-18

Improved Spring Load Restriction Guidelines Using Mechanistic Analysis

Research

Technical Report Documentation Page

1. Report No.	2.	3. Recipient's Accession No.
MN/RC –2000-18		

4. Title and Subtitle	5. Report Date
IMPROVED SPRING LOAD RESTRICTION GUIDELINES USING MECHANISTIC ANALYSIS	July 2000
	6.
7. Author(s) Jill M. Ovik, David A. Van Deusen, John A. Siekmeier	8. Performing Organization Report No.
9. Performing Organization Name and Address Minnesota Department of Transportation Office of Materials and Road Research 1400 Gervais Avenue, M.S. 645 Maplewood, Minnesota 55109	10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. (C) 2000-XXX
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research Services 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155	13. Type of Report and Period Covered Final Report 1999 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This project used research to develop more effective criteria for placement and removal of spring load restrictions (SLR). Researchers investigated a method that uses a thawing index equation based on air temperatures to predict thawing events. Results showed that adjusting the reference temperature improved the spring-thaw prediction for Minnesota.

Researchers compared historical SLR posting dates from 1986 through 1998 to the dates predicted using this new technique and to falling weight deflectometer and in situ instrumentation readings from 15 flexible pavement test sections in Minnesota. According to results, there was typically a week or more delay from the time that SLR should have been placed until actual posting of restrictions, which caused damage that could have been prevented. Based on testing performed on pavement sections across the state, the typical period required for pavement base and subgrade layers to regain sufficient strength to support heavy truck loads was eight weeks.

In 1999, the Minnesota Department of Transportation adopted the improved procedure for placing and removing SLR. The policy uses actual and forecasted average daily temperature to determine timing of SLR. With the SLR duration is fixed at eight weeks, it is easier to plan for the end of the restriction period. Researchers estimate an increase of 10 percent in a typical low-volume asphalt road's life with implementation of the improved SLR procedures, resulting in a potential savings of more than $10 million annually.

17. Document Analysis/Descriptors		18. Availability Statement
spring load restrictions	flexible pavement evaluation	No restrictions. Document available from:
thaw weakening	frost	National Technical Information Services,
freeze-thaw	road restrictions	Springfield, Virginia 22161

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	87	

IMPROVED SPRING LOAD RESTRICTION GUIDELINES USING MECHANISTIC ANALYSIS

FINAL REPORT

Prepared by

Jill M. Ovik, E.I.T.
Research Project Engineer

John A. Siekmeier, P.E.
Research Project Engineer

David A. Van Deusen, P.E.
Research Operations Engineer

Minnesota Department of Transportation
Office of Materials and Road Research
1400 Gervais Avenue, Mail Stop 645
Maplewood, Minnesota 55109

July 2000

Published by:

Minnesota Department of Transportation
Office of Research and Strategic Services
First Floor
395 John Ireland Boulevard, Mail Stop 330
St. Paul, Minnesota 55155

ACKNOWLEDGEMENTS

This work was funded in part by the Minnesota Local Road Research Board and their support is gratefully acknowledged. The authors would like to express their sincere appreciation to the Minnesota Department of Transportation (Mn/DOT) Office of Materials & Road Research personnel who collected the deflection and environmental field data and assisted with the analyses in this paper: Jennifer Cohoon, Greg Johnson, Heather Kienitz, Greg Larson, Ryan McKane, Mike Miezwa, Chris Nadeau, Bill Pirkl, Maria Radermacher, Ruth Roberson, Tom Zeller, and John Zollars. The authors would also like to thank Jack Herndon, Minnesota Road Research Project (Mn/ROAD) site manager, for his assistance in orchestrating the field studies. This research was made possible with the help of many Mn/DOT employees outside the Mn/ROAD Section. Duane Young, Dave Beberg and Dave Bullock, Pavement Design; Ken Hoeschen and Ken Straus, State Aid; Dennis Anderson, Engineering Services; and Dave Janisch, Pavement Management provided complete and timely contributions that are greatly appreciated. The University of Minnesota developed the mechanistic-empirical pavement design software. The University of Washington developed the original thawing index criterion, which has been modified by Mn/DOT. Personnel from the U.S. Army Cold Regions Research and Engineering Laboratory also played a significant role in the field data collection.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

In regions of the United States where pavements are constructed in freeze-thaw environments spring load restrictions (SLR) are typically used as a preservation strategy, and have been used in Minnesota since 1937. This is because during the spring, pavement layers generally are in a saturated, weakened state due to partial thaw conditions and trapped water. SLR are placed to allow the trapped water to drain and the pavement to recover. The critical time for placing SLR is when the pavement first thaws and the stiffness of the base layer is low. Thus, proper measurement and prediction of freeze-thaw events are crucial to a successful load restriction strategy.

In Minnesota, SLR impact many more miles of the county state aid, county, township and municipal roadway systems than the state trunk highway (TH) system. The percentage of TH subject to SLR is approximately 13 percent of the 11,900 miles of the state network. On the other hand, out of 30,300 miles of the total county state aid highway (CSAH) system, only 3 percent are 10-ton or greater, and thus, 97 percent are subject to SLR. County, township and municipalities are required to follow state recommendations on load restriction posting and removal dates, unless roads are posted otherwise.

The past SLR procedure practiced by the Minnesota Department of Transportation (Mn/DOT) was developed by a Task Force in 1986. The procedure for load restriction placement involved monitoring: 1) conditions that indicate the potential for spring load-related damage, such as seeping water near cracks, 2) thaw depth measurement using frost tubes or probe rods in shoulder, and, 3) weather conditions and forecasts. The guidelines for lifting the load restrictions were to be based in part on deflection measurements. However, it was found that basing the end of SLR on deflection measurements was not practical due to the large amount of roads that needed to be tested weekly, also the logistics involved in setting up lane closures, travel, equipment failures and other reasons.

In the past SLR procedure, District Engineers would reach agreement that SLR should be placed in a certain zone and a 7-day notice was given to the public. The duration of SLR would vary each year from about 7 to 9 weeks depending on the roadway condition. Unfortunately, partially due to the 2 to 4 days needed for the districts to meet a consensus to apply SLR and partially due to the required 7-day notice, SLR were placed 7 to 10 days too late, thus missing the critical initial thaw-weakened period. The additional damage due to premature pavement deterioration resulted in additional direct costs to the State of Minnesota and to local units of government. Also, there were additional user costs associated with vehicle damage, increased travel time due to pavement condition, and lost time due to construction detours.

The study documented in this report was undertaken to evaluate criteria used to predict when to place and remove SLR. The objectives were to (1) develop improved predictive equations for estimating when to begin and end SLR, (2) investigate changes in pavement strength in relation to freeze-thaw events, and (3) compare aggregate base strength-recovery characteristics and assess their performance.

First, previous research concerning the placement and removal of SLR was reviewed. The Washington State Department of Transportation (WSDOT) developed a thawing index equation based on air temperatures. This procedure recommended that restrictions be placed once the cumulative thawing index (TI) reaches 15 to 30°C-days (25 to 50°F-days). The TI is computed as the summation of the average daily temperature subtracted from a reference temperature (suggested T_{ref} = -1.7°C (29°F)). The suggested length of the SLR is also determined from air temperature data.

Second, research in Minnesota found that adjusting the reference temperature improved spring-thaw prediction to better fit Minnesota conditions. The revised Mn/DOT equation uses a T_{ref} = -1.5°C (29.3°F) on February 1, and decreases by 0.56°C (1°F) per week during February and March. This relationship is the result of increasing solar radiation through the spring. An equation was developed to determine the optimal length of the SLR period and was compared to WSDOT's guidelines. Based on testing performed on pavement sections across the state, it was found that the typical period required for the pavement base and subgrade layers to regain sufficient strength to support heavy truck loads was eight weeks. Thus, the length of the SLR period was fixed at 8 weeks with the additional benefit that the fixed period allows transporters the ability to plan for the end of the SLR period.

The third step was to compare the posting dates predicted using the new SLR technique to historical posting dates from 1986 through 1998. The predicted and actual SLR placement dates were compared to falling weight deflectometer and in situ instrumentation readings at the Minnesota Road Research Facility (Mn/ROAD) and other sites in Minnesota. It was found that there was typically a week or more delay from the time that SLR should have been placed until restrictions were actually posted. This delay caused pavement damage that could have been prevented.

The final step in the process was to implement the new Mn/DOT procedure for placing SLR. The new policy was adopted for the spring of 1999 and uses actual and forecasted average daily temperature to determine when SLR should begin. Beginning in the spring of 2000 a new Minnesota law specifies that county, township and municipal roads will begin and end SLR in common with the state TH system, unless these roads are posted otherwise.

It is estimated that a typical low volume asphalt road's life will be increased by about 10 percent due to implementation of the improved SLR procedures. The potential savings resulting from improved load restriction placement are expected to be substantial since in Minnesota there are about 39,000 miles of paved roads that do not meet the 10-ton spring load design standard. The vast majority of these roads are paved with asphalt concrete, which has an annual construction and overlay cost of about $12,000 per mile per year. A 10 percent reduction in the life results in an additional annual cost of about $500 per mile per year resulting in an approximate annual savings of more than $10,000,000 statewide.

CHAPTER ONE

INTRODUCTION

In regions of the United States where pavements are constructed in freeze-thaw environments, spring load restrictions (SLR) are typically used as a preservation strategy. During the spring, pavement layers generally are in a saturated, weakened state due to partial thaw conditions and trapped water, which results in increased damage and a shorter useful life unless the loads are reduced. Much of the damage that occurs to the pavement is related to the magnitude and frequency of the load applied and the stiffness of the materials.

The time in which a typical pavement thaws depends on the location of the site, solar radiation, drainage, air temperature, rainfall, soil type, moisture and thermal properties. In general, the pavement thaws from the surface, down. As the average daily air temperature and declination of the sun increase during the spring, the temperature of the surface layer begins to rise. The increase in temperature migrates through the surface layer and into the unbound aggregate base layer, which begins to thaw. For a flexible pavement with a fine-grained subgrade, the moisture in the base becomes trapped between two impermeable layers [1]: the asphalt concrete layer and the frozen, fine-grained subgrade layer. Since the excess water cannot drain easily, the base layer decreases in stiffness and is considerably softer during the spring – thaw period. SLR are placed as a method of protecting the base layer from higher loads during the spring-thaw period.

The critical time for SLR is when the pavement first thaws and the stiffness of the base layer is low. Thus, proper measurement and prediction of freeze-thaw events is crucial to a successful load restriction strategy. The exact time at which SLR should be implemented and removed depends on many factors such as the pavement structure, soil type, traffic, topography, frost depth, air temperature, and drainage conditions. However, for a SLR policy to be implemented successfully it must be as simple as possible, yet include the most important factors common to the greatest number of roadway miles.

In Minnesota, SLR impacts many more miles of the county state aid, county, township and municipal roadway systems than the state trunk highway (TH) system. Approximately 13 percent of the 11,900 miles of the state network are subject to SLR. On the other hand, 97 percent of the 30,300 miles of the total county state aid highway (CSAH) system are subject to SLR. County, township and municipalities are required by law to follow state recommendations on load restriction beginning and removal dates unless they post signs.

In the past Minnesota SLR procedure, District Engineers would reach agreement that SLR should be placed in a certain zone and a 7-day notice was given to the public. The duration of SLR would vary each year from about 7 to 9 weeks depending on the roadway condition. Unfortunately, partially due to the 2 to 4 days needed for the districts to meet a consensus to apply SLR and to the required 7-day notice, SLR were placed 7 to 10 days too late, thus missing the critical initial thaw-weakened period. The additional damage due to premature pavement deterioration resulted in additional direct costs to the State of Minnesota and to local units of government. Also, there were additional user costs associated with vehicle damage, increased travel time due to pavement condition, and lost time due to construction detours.

This report documents the method used to improve Minnesota's SLR policy. It is shown that the new procedure adopted by the Minnesota Department of Transportation (Mn/DOT) in 1999 is a simple and more effective method for placing and removing SLR. It is estimated that a typical low volume asphalt road's life will be increased by about 10 percent due to implementation of the improved SLR procedures, resulting in a potential savings of more than $10,000,000 annually.

Background

Records in Minnesota indicate that with the formation of the State Highway Department, the Highway Commissioner was given the authority to impose load restrictions on state highways to maintain the integrity of the infrastructure [2]. In 1947, the seasonal restrictions were fixed according to the calendar date, starting March 20 and ending May 15. Local authorities were allowed to either prohibit the operation or restrict the weight of vehicles on any highway if it could be seriously damaged or destroyed due to rain, snow or other climatic conditions.

In 1986, a Mn/DOT Task Force [3] developed a SLR policy in which a 7-day notice of SLR was given to the public after the following criteria were reached: 1) thaw had penetrated to a depth greater than 150 mm (6 in.), 2) forecasted weather conditions looked favorable for continued thaw, and 3) agreement was reached between the various districts within the same frost zone to begin SLR. The zones used in Minnesota for placing SLR are shown in Figure 1 and the dates that SLR were placed and removed between 1986 ad 2000 are shown in Table 1. Unfortunately, partially due to the 2 to 4 days needed for the districts to meet a consensus to apply SLR and partially due to the required 7-day notice, SLR were placed 7 to 10 days too late, thus missing the critical initial thaw-weakened period. The damage resulted in additional direct costs to the State of Minnesota and to local units of government due to the premature pavement deterioration. There were additional user costs associated with vehicle damage, increased travel time due to pavement condition, and lost time due to construction detours.

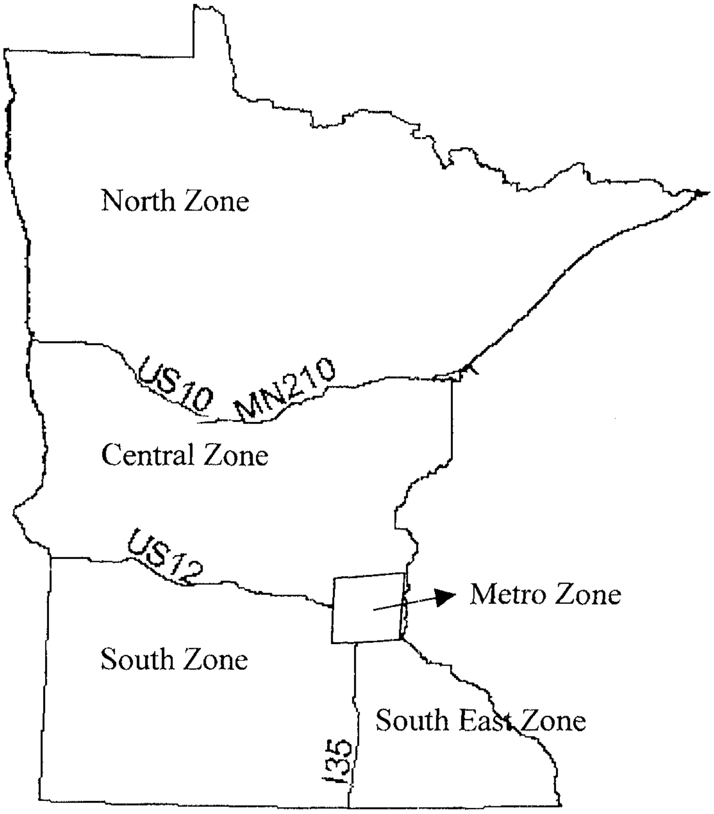


Figure 1. Five zones used in Minnesota to place and remove SLR.

The previous guidelines for ending SLR were based on deflection measurements and other observations. The 1986 report suggested that weekly deflection measurements should be collected once the thaw was well under way and the recommended end for SLR was three weeks after the maximum deflection was observed. It had been found that the maximum pavement deflection occurs when the thaw depth is roughly 1.0 m (40 in.) below the surface and that there is a correlation between maximum deflection and thaw depth. Basing the end of SLR on deflection measurements has a distinct disadvantage due to the large number of roads that need to be tested weekly, also the logistics involved in setting up lane closures, travel time, equipment failures and other reasons. Another disadvantage of using deflection measurements was the large variability in deflections due to rainfall events and temperatures that were difficult to account for in weekly testing.

Finally, the 1986 report recommended that further research was needed to create a simple, accurate model to identify when to begin and end SLR. The report that follows documents research that began in 1996. The data were obtained from the Minnesota Road Research facility (Mn/ROAD) and other locations throughout Minnesota.

Table 1. Placement and removal dates of SLR in Minnesota (1986 - 2000).

Zone	1986		1987		1988		1989		1990	
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
Metro	17-Mar	28-Apr	4-Mar	13-Apr	14-Mar	25-Apr	22-Mar	1-May	14-Mar	25-Apr
South	11-Mar	9-May	20-Feb	27-Apr	14-Mar	4-May	15-Mar	8-May	5-Mar	7-May
South East	17-Mar	12-May	20-Feb	27-Apr	14-Mar	9-May	22-Mar	8-May	12-Mar	7-May
Central	19-Mar	12-May	6-Mar	27-Apr	14-Mar	4-May	27-Mar	8-May	14-Mar	7-May
North	24-Mar	19-May	13-Mar	6-May	21-Mar	16-May	29-Mar	15-May	19-Mar	14-May
Zone	1991		1992		1993		1994		1995	
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
Metro	18-Mar	25-Apr	2-Mar	22-Apr	12-Mar	3-May	14-Mar	4-May	17-Mar	4-May
South	13-Mar	6-May	2-Mar	4-May	12-Mar	17-May	14-Mar	16-May	17-Mar	15-May
South East	18-Mar	9-May	4-Mar	7-May	12-Mar	17-May	14-Mar	16-May	17-Mar	15-May
Central	17-Mar	6-May	9-Mar	5-May	15-Mar	17-May	21-Mar	16-May	17-Mar	15-May
North	25-Mar	13-May	11-Mar	11-May	15-Mar	17-May	21-Mar	23-May	17-Mar	24-May
Zone	1996		1997		1998		1999		2000	
	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
Metro	18-Mar	13-May	17-Mar	12-May	25-Feb	27-Apr	3-Mar	28-Apr	25-Feb	21-Apr
South	15-Mar	20-May	17-Mar	12-May	23-Feb	27-Apr	2-Mar	27-Apr	25-Feb	21-Apr
South East	15-Mar	20-May	12-Mar	16-May	23-Feb	27-Apr	3-Mar	28-Apr	25-Feb	21-Apr
Central	18-Mar	20-May	17-Mar	19-May	25-Feb	27-Apr	3-Mar	28-Apr	25-Feb	21-Apr
North	20-Mar	28-May	27-Mar	21-May	25-Feb	E:27-Apr	18-Mar	13-May	26-Feb	22-Apr
						W:11-May	New Policy Enacted			

In the time since the 1986 Task Force completed their report, an extensive pavement testing facility was constructed in central Minnesota that enables researchers to investigate the effects of freeze-thaw events on flexible pavement structures. Construction of Mn/ROAD was completed and opened to traffic in 1994. Of particular use for this study was the seasonal load and environmental testing conducted on the low-volume road (LVR) flexible pavement test sections (TS). The LVR loop is subject to traffic loads from a 5-axle tractor-trailer that drives at 80,000 lbs. on the inside lane (80K-lane) four days a week, and 102,000 lbs. on the outside lane (102K-lane) 1 day a week. To date approximately 80,000 equivalent single axle loads (ESALs) have been applied in each lane since the truck began operating in 1994. Also included in this study were seven other test sections located in District 2 and 4 of Minnesota (Table 2).

Table 2. Test sections used in thaw-weakening studies.

Area	Route	AC, mm	Aggregate Base, mm	Subgrade[a]
District 2A	71	190	-[b]	Sand
District 2A	72	150	140	Silty-clay
District 2B	102	140	450	Silt
District 4	CR 58	240	-[b]	Sandy-clay
District 4	9	100	305	Clay
District 4	29	230	-[b]	Sandy-clay
District 4	104	180	430	Clay
Mn/ROAD	24	75	100	Sand
	25	125	-[b]	Sand
	26	150	-[b]	Silty-clay
	27	75	280	" "
	28	75	330	" "
	29	125	250	" "
	30	125	305	" "
	31	75	405	" "

[a]Mn/DOT classification
[b]Full-depth asphalt section.

The LVR at Mn/ROAD consists of seventeen different flexible and rigid pavement design test sections that are 152 m (500 ft) in length. Twelve of the LVR test sections are flexible pavement designs with a hot-mix asphalt (HMA) surface layer thicknesses that range between 75 and 150 mm (3 and 6 in.). Eight of these test sections are used in this study. Of these eight test sections, six are conventional designs with varying thicknesses of aggregate base and subbase, and two sections are full-depth HMA sections (Figure 2). Extensive laboratory and field testing of the Mn/ROAD materials has been done and is summarized elsewhere [4].

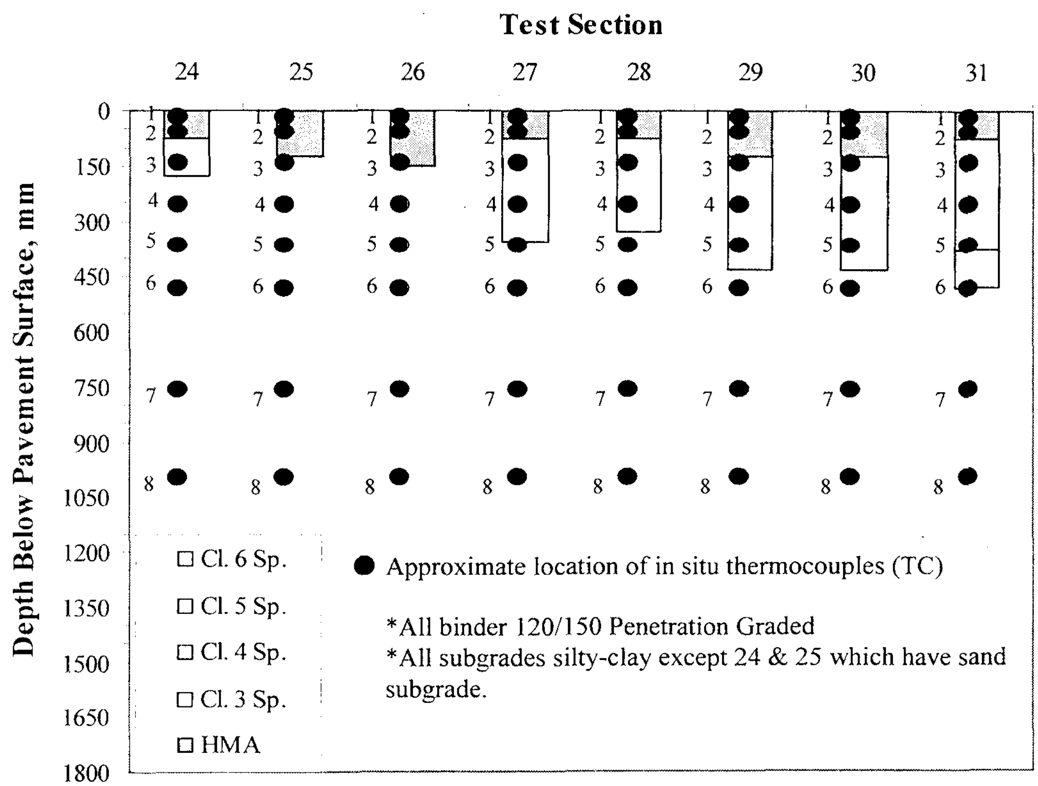


Figure 2. Mn/ROAD test sections with locations of in situ thermocouple sensors.

The base and subbase materials are dense-graded sand and gravel mixtures of varying quality. The aggregate base materials at Mn/ROAD are referred to as Class 3 Special (Cl. 3 Sp.), Class 4 Special (Cl. 4 Sp.), Class 5 Special (Cl. 5 Sp.) and Class 6 Special (Cl. 6 Sp.). The label "Special" is used because the gradation specifications for these materials were slightly different than Mn/DOT's normal specifications. The fines content in the aggregate bases range from over 10 percent (Cl. 3 Sp.) down to less than 6 percent for the Cl. 4, 5, and 6 Sp. The Cl. 6 Sp. base material is a 100 percent crushed granite.

Six of the eight sections are constructed on a sandy lean clay (USCS CL), which is the native soil at the site and has a design R-value of 12. The other sections (TS 24 and 25) are constructed on 2.1m (7 ft) of an imported sand subgrade that is classified as poor to medium-graded sand (USCS SP-SM) and has a design R-value of 70.

Deflection and environmental sensor testing has been conducted at Mn/ROAD on a regular basis and the data from 1993 to 1999 are used in this report. This report focuses mainly on lanes 1, 2, 6 and 7 that correspond to the location of falling weight deflectometer (FWD) testing on the LVR. Lanes 1 and 2 are located in the outer wheel path (OWP) and mid lane of the 80K-lane, respectively. Lanes 6 and 7 are located in the OWP and mid lane of the 102K-lane, respectively. Two weather stations collect temperature, atmospheric pressure, precipitation, relative humidity, solar short-wave radiation, wind direction and wind speed data.

Objectives

The objectives of this research were to:

1. Develop improved predictive equations for estimating when to begin and end SLR.
2. Investigate changes in pavement strength in relation to freeze-thaw events.
3. Compare aggregate bases strength-recovery characteristics and assess their performance.

Organization of Report

Chapter One introduces the topic of SLR. Chapter Two discusses previous research concerning methods of placing and removing SLR by various agencies. Chapter Three shows the approach used to improve Minnesota's SLR policy. Chapter Four discusses the results from this methodology. Chapter Five estimates the potential savings that result from implementation. Chapter Six provides the final summary, conclusions and recommendations.

CHAPTER TWO

PREVIOUS RESEARCH

Introduction

This chapter presents material relevant to SLR including various SLR policies and procedures, and research done to determine the optimal placement date and length of the SLR period in other states, provinces and countries. These practices varied from the sole use of engineering judgement and experience, to the inclusion of analytical methods such as deflection testing and thaw prediction equations. An approach taken in Norway to eliminate SLR is also presented.

SLR Policies

Several states (Figure 3), Canadian provinces and European countries use SLR when economic constraints prevent reconstructing or overlaying the pavement to withstand greater loads during the spring [5]. The frost line shown in Figure 3 is the approximate geographic boundary between the states that are susceptible to freeze-thaw conditions and the states that are less susceptible. SLR typically begin in late February or early March, and last through April or May, usually spanning an eight-week period or more. The methods used to determine when to place and remove the restrictions vary between the states and within each state, depending on the local government. The methods include one or a combination of the following:

- Setting the date by the calendar each year.
- Engineering judgement.
- Pavement history.
- Pavement design.
- Visual observations, such as water seeping from the pavement.
- Restrict travel to night-time hours (appropriate for unpaved roads only).

- Daily air and pavement temperature monitoring.
- Frost depth measurement using drive rods, frost tubes, and various electrical sensors.
- Deflection testing.

(note: the method of reducing vehicle speed is no longer used in South Dakota since it was found to increase damage to the pavement structure)

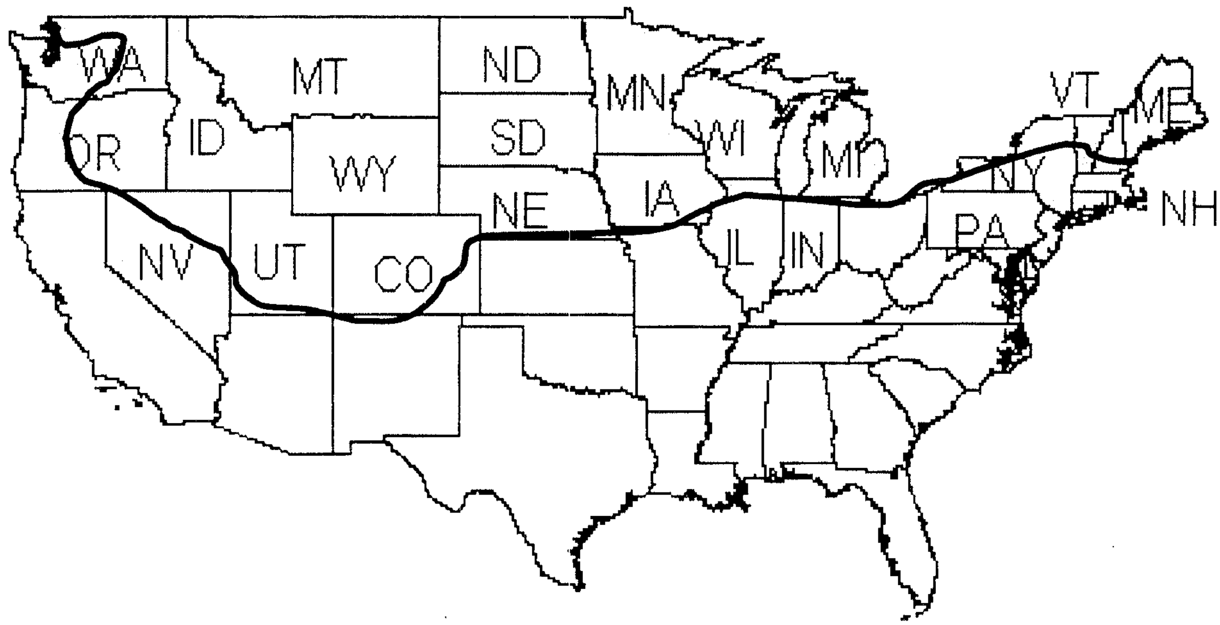


Figure 3. States with spring load restrictions on state, county or city roads and the approximate frost line.

Researchers have investigated several methods for placing and removing SLR for areas in freeze-thaw environments. Some research has been done to relate pavement deflections to the damage potential in the spring with varying success [6, 7, 8, 9, 10, 11]. Deflection testing is a difficult method to use due to relatively rapid changes in conditions and the large geographic distance between test locations.

The Washington Department of Transportation (WSDOT) has done a great deal of research relating average air temperature to thaw depth in the pavement structure [6, 11, 12, 13, 14, 15, 16]. This method uses simple equations called the freezing index and the thawing index to predict when to place and remove SLR.

Freezing and Thawing Index

The depth of frost and thaw depends in part on the magnitude and duration of the temperature differential below or above freezing at the ground surface [11]. The freezing or thawing index (FI and TI, respectively) can be used to quantify the intensity of a freezing or thawing season. The FI (Equation 1) is defined as the positive cumulative deviation between a reference freezing temperature and the mean daily air temperature for successive days. The TI (Equation 2) is the positive cumulative deviation between the mean daily air temperature and a reference thawing temperature for successive days. They are calculated as follows [11].

$$FI = \Sigma(0^{\circ}C - T_{mean}) \quad (1)$$

Where T_{mean} = mean daily temperature, $^{\circ}C = 1/2(T_1 + T_2)$, and

T_1 = maximum daily air temperature, $^{\circ}C$,

T_2 = minimum daily air temperature, $^{\circ}C$.

$$TI = \Sigma(T_{mean} - T_{ref}) \quad (2)$$

Where T_{ref} = reference freezing temperature that varies as pavement thaws, $^{\circ}C$.

The 1986 Mn/DOT task force also investigated the use of air temperature as a means to estimate the approximate time of thaw initiation in Minnesota [3]. They found that, based on historical maintenance records, the TI at the beginning of SLR ranged from about 10 to 25°C-days (18 to 45°F-days) for the entire state. There was significant variability in the range of values (standard deviation between 17 to 22°C-days (30 to 40°F-days)) due to the unpredictability of weather and the mobilization time required for posting restrictions. The task force concluded that further investigation was needed before the TI could be used to predict when thaw begins.

Five State Area SLR Information

The following sections briefly describe the policy for SLR for each state investigated. A summary of the surrounding five-states (North Dakota, South Dakota, Iowa, Wisconsin and Michigan) is shown in Table 3. This was the best available data compiled from telephone conversations and written policies received from the Department of Transportation. Individual counties, cities, and townships were not surveyed directly, however, it seemed common for the counties and cities to follow state policies.

The five states differ in SLR policies, however some similarities exist. They typically start SLR as early as February 28 (South Dakota) and as late as March 15 (North Dakota). The typical duration is fairly uniform at 8 to 9 weeks. North Dakota restricts 10 percent of the trunk highway (TH) system to varying weight limits and South Dakota restricts 12 percent of the TH system to 6 and 7-ton axle weight limits. Iowa and Wisconsin have 10 to 13 percent of their TH systems restricted such that no overload permits are allowed. Michigan restricts less than 5 percent of their TH system such that 30 percent of the vehicle weight is restricted for hot mix asphalt (HMA) surfaced roads. The most common methods used to determine weight limits were deflection testing and experience.

Included in Table 3 is information on the uniformity of SLR enforcement between and within the states. This is an important issue since at the local level, non-uniform enforcement can give an unfair advantage to transporters in one area over another. Also, it may be difficult to convict an overloaded transporter since many municipalities do not enforce and understand the need for SLR to preserve the integrity of the pavements [17].

Table 3. Summary of the surrounding 5 - state area.

Typical Beginning of SLR		% of Total THs Restricted	
North Dakota	15-Mar	North Dakota	Approx. 10 %
South Dakota	28-Feb	South Dakota	12 %
Iowa	1-Mar	Iowa	10 %
Wisconsin	10-Mar	Wisconsin	13 %
Michigan	Early March	Michigan	< 5 %
Typical End of SLR		**Who Enforces SLR County Limits**	
North Dakota	1-Jun	North Dakota	Sheriff
South Dakota	27-Apr	South Dakota	Sheriff
Iowa	1-May	Iowa	State Patrol/Sheriff
Wisconsin	10-May	Wisconsin	Sheriff
Michigan	Late May	Michigan	Motor Carrier Office
Typical SLR Period, weeks		**Enforcement Uniformity**	
North Dakota	8 to 9	North Dakota	Somewhat non-uniform
South Dakota	8.3	South Dakota	Somewhat non-uniform
Iowa	Approx. 8	Iowa	Somewhat non-uniform
Wisconsin	8.7	Wisconsin	Somewhat non-uniform
Michigan	Approx. 8	Michigan	Somewhat non-uniform
Types and Magnitude of Restrictions		**How is Magnitude of Restrictions are Determined**	
North Dakota	Differs between TH & County Roads.	North Dakota	Deflection Tests & Experience
South Dakota	6- & 7- ton axles	South Dakota	Deflection Tests & Experience
Iowa	No Overloads	Iowa	Road Rater & Experience
Wisconsin	No Overloads	Wisconsin	Deflection Tests & Experience
Michigan	30% for AC pavement	Michigan	Blanket 30%, Experience
Recipient of Fines			
North Dakota	State or County General Hwy Fund		
South Dakota	Counties		
Iowa	Counties		
Wisconsin	State, county, school districts, other		
Michigan	Libraries		

SLR Policies: Engineering Judgement and Experience

Several states and Canadian provinces rely on engineering experience and visual observation to determine the beginning and length of the SLR period. Visual observations can include water seeping through cracks in the pavement from the subsurface layers as traffic loads are applied, rapid deterioration of the surface layer, and soft shoulders. These states and provinces are:

- North Dakota
- Idaho
- Maine
- Montana
- New Hampshire
- Oregon
- New York
- Iowa
- Wisconsin
- Michigan
- Illinois
- Manitoba
- Ontario

Manitoba sets the length of the SLR period according to the calendar day, regardless of the thawing condition. This typically last six to eight weeks in northern Manitoba and ten weeks in southern Manitoba. However, if the conditions are such that no significant thawing has occurred, the enforcement of SLR are delayed. This province and several others are currently researching the method used by Mn/DOT and WSDOT to place and remove SLR for possible implementation.

SLR Policies: Analytical Methods

The following states use analytical methods in addition to engineering judgement and experience to place and remove SLR:

- Washington
- Alaska
- Minnesota
- South Dakota

The dates and duration of the SLR are determined using several methods including one or more of the following (government organizations have tailored the methods specifically to their region):

- Deflection tests to determine stiffness.
- Various electrical sensors to measure frost depth.
- Average daily air and pavement temperature to predict thawing.
- Pavement design capacity, adjusted for age and history of restrictions.
- Visual observation of pavement surface deterioration and water seeping from cracks.
- Engineering experience and judgement are used in all pavement evaluations.

Norway's Method of Eliminating SLR

A study was conducted in Norway to determine the effects of removing all SLR [18]. Norway's highway system consisted of SLR on 50 percent of the 16,000 miles of primary road system and 80 percent of the 17,000 miles of secondary roads. The SLR period began when the pavements thawed between 125 and 255 mm (5 in. and 10 in.), and ended when the thaw reached an approximate depth between 1015 and 1270 mm (40 in. and 50 in.). The length of the SLR period was approximately 8 weeks. The estimated extra annual cost of lifting all SLR was $11 million (U.S.) for the 8-ton system, and $20 million (U.S.) for the 10-ton system. However, the estimated annual economic gain was $44 million (U.S.), resulting in a $24 million (U.S.) annual benefit.

Beginning in 1995, all SLR were removed, bringing the whole system to a 10-ton capacity. Norway's construction budget was increased by $20 million (U.S.) to maintain 10 and 15 year service lives of primary and secondary roads. The increased budget avoided potential annual loss of $28 million (U.S.) due to vehicle damage, accidents and fuel costs resulting from damaged and poorly maintained roads. After three years, the increased budget had covered the increased damage including some complete reconstruction.

SLR Research of Analytical Methods

This section discusses research that has been done using analytical methods to predict the beginning and length of the SLR period. Several researchers have attempted to relate pavement deflection to spring damage with varying success. A study of Illinois and Minnesota data by Texas A&M found that deflection data correlated to observations of frost movement and corresponding structural changes [7]. A study in Washington showed a better correlation between critical thaw conditions and layer stiffness rather than deflections [6]. WSDOT has also done research using the FI and TI to predict when to place SLR and the length of the SLR period. In a study performed in Norway, it was found that deflections were correlated to thaw begin/end dates. For sections built on clay subgrades, the maximum deflection routinely occurred near the thaw-end date. Observations were more variable in silty subgrades [9, 10]. Janoo and Berg [19, 20, 21] found good correlations between the area and deflection ratios and the depth of thaw but they cautioned against the general application of the resulting equations due to the limited size of their database. Finally, research done on U.S. Forest Service roads in Montana [22] was able to identify the thaw-weakened period using pavement temperature.

Texas A&M University Research

Scrivner et al. [7] found that deflection data correlated to observations of frost movement and the corresponding structural changes. In this study, 24 test sections located in Illinois and Minnesota were monitored for frost and deflection data for one year. It was found that a rapid increase in deflections occurred coinciding with the disappearance of frost from the pavement structure. The changes in deflection were modeled using the surface curvature index (SCI) defined in the Texas study as the difference between deflection values measured from the first and the second sensors (DF_1 - DF_2) located 305 and 610 mm (12 and 24 in.) from the load, respectively. The ratio of the SCI in the spring and in the summer was used to create guidelines for placing SLR and the SCI was also used to determine the allowable load for a pavement structure.

WSDOT Research

Rutherford [6] performed an analytical study of hypothetical pavement structures that were subjected to freezing and thawing cycles. The critical responses that indicated weakened and recovered conditions for pavements with thicknesses of 50 and 100 mm (2 and 4 in.) were calculated using material layer parameters representing four conditions: frozen, partially thawed, fully thawed, and recovered. The calculated spring pavement responses were then related to summer (recovered) values. The research showed that the spring deflections relative to summer deflections were not a reliable indicator of critical thaw conditions and that the damage potential was more closely related to layer stiffness rather than maximum deflection. In addition, it was found that the damage potential calculated from the vertical subgrade strain was greater than the fatigue damage potential in the 100 mm (4 in.) thick sections during the spring-thaw period.

A significant amount of research has also been done by WSDOT showing that air temperature can be used to predict critical thaw periods [6, 11, 12, 13, 14, 15]. It was found that thawing had penetrated the base to a depth of about 150 mm (6 in.) at a TI of 15°C-days (approximately 25°F-days). To optimally place SLR, it was recommended that SLR should be placed when the TI of 15°C-days (25°F-days) is attained and must be in place by 30°C-days (50°F-days).

WSDOT also investigated relationships between the FI, TI, and the thaw duration (D) that resulted in Equations 3 and 4 [12]. These regression equations were developed from the results of heat-flow simulations that were designed to model fine-grained subgrade soils and a FI range from about 200 to 1000°C-days (360 to 1800°F-days).

$$D = 25 + 0.018(FI) \tag{3}$$

where D = thaw duration (days), and

FI = Freezing Index, °C-days.

$$TI = 0.3(FI) \tag{4}$$

where FI = Freezing Index, °C-days or °F-days.

It is important to note that there are two concepts described here: the thaw duration and the length of the SLR period. It was found that Equations 3 and 4 predict the length of the thaw duration to be longer than the actual thaw duration, thus, WSDOT adopted the equations as a means of predicting the length of the SLR period for the state of Washington. The extra time included in the SLR period would allow for the base layer to recover after it has completely thawed.

Satellite Studies Using Freezing and Thawing Indices

Yesiller, et. al. [23], presented the results of work done in Wisconsin for the past decade. They compared predicted freezing season begin and end dates as well as the length of the SLR period using the WSDOT model against measurements made with frost tubes. It was verified that the WSDOT equations were better for fine-grained rather than granular subgrade materials. They also showed that the frost tubes indicate earlier thaw than the WSDOT method, meaning that the WSDOT method predicted a longer SLR period than the actual thaw duration.

Wilson [24] conducted a study for the South Dakota DOT in which it was found that air temperature data should be used to predict placement and removal SLR dates based on WSDOT criterion. Subsurface monitoring using temperature sensors was done. Based on the results from that study it was recommended to conduct field calibrations of the WSDOT equations for South Dakota.

Norway Research

A 5-year study was conducted using deflection measuring equipment and frost probes [9, 10]. The decision of when to remove SLR was dependent on the total frost depth and ratio between permitted axle load during spring thaw and summer. The date when SLR was removed was expressed in terms of the weeks past the date of critical thaw depth. Deflection, heave, and frost depth measurements were made in a field study with sections constructed on both clay and silt subgrades. The results of the field tests indicated that the maximum deflections on the clay subgrade sections occurred consistently at the end of the thaw duration. For the silt sections the maximum occurred irregularly during or after the thaw. Attempts were made to derive relationships between the maximum deflections and other parameters. Good correlations were found for the clay sections but not for the silt.

CRREL Research

Janoo and Berg [19, 20, 21] conducted a small-scale test in the US Army Corps of Engineers Frost Effects Research Facility on four different flexible pavement test sections. The objective of this study was to obtain data on the seasonal changes in pavement layer strength. FWD tests were conducted during several freeze-thaw cycles. Attempts were made to correlate the following deflection parameters with the thaw depth: impulse stiffness modulus, basin area, center sensor ratio, and fourth sensor ratio.

It was found that the impulse stiffness modulus did not provide an indication of thaw depth. Ratios for the center and fourth deflection sensors were calculated to compare deflections during the freeze thaw cycle to the initial deflections measured before the freeze thaw cycle. Good correlations were found between the area and deflection ratios and the depth of thaw, but the authors cautioned against the general application of the resulting equations due to the limited size of their database. They also investigated the effects of pavement temperature on the overall center deflection during the thaw period by doing an analytical study on a hypothetical section. This showed that during the spring thaw period about 10 percent of the deflection is attributed to the HMA surface layers. They concluded that no temperature adjustment needed to be applied to the measured deflections during this period.

U.S. Forest Highway Research in Montana

Field tests done on forest service roads in Montana by McBane and Hanek [22] showed that the thaw-weakened period could, in most cases, be identified by temperature. Their data showed that thawing commenced when pavement temperatures neared 0°C (32°F) at the asphalt/base interface. It was concluded that rapid strength loss occurred as the base layer thawed pointing out the importance of timely placement of SLR.

Summary

SLR are used as a method of preventing premature pavement deterioration to the structures from heavy loads during the critical spring - thaw period when the pavement structure is at its weakest. A great deal of research has been conducted in an effort to optimally place SLR and to determine the length of the SLR period. Over the years, the methods developed have become more accurate and easier to use. The basis of the methods for placing and removing the SLR has evolved from observing the pavement structure for signs of spring-thaw distress, to measuring pavement deflections, and more recently, to predicting thaw from air temperature data.

A majority of the states place and remove SLR using engineering judgement, visual observations and fixed calendar dates. Currently, Washington, Alaska, South Dakota and Minnesota use analytical methods including deflection tests, measurements of thaw depth, and average daily air and pavement temperatures to supplement knowledge about the pavement structure and history, visual observation and engineering experience.

CHAPTER THREE

RESEARCH APPROACH

Introduction

The approach used in this study was to evaluate Minnesota's SLR procedure, which had last been reviewed in 1986, and suggest improvements that would result in a more simple and accurate SLR procedure. The SLR guidelines followed by WSDOT maintenance personnel were analyzed and applied to Minnesota's highway system. The basic premise of WSDOT's guidelines is to impose SLR once the TI reached between 15 and 30°C-days (25 and 50°F-days). The critical depth of thaw at this time is related to the spring-thaw weakened period for flexible pavements. Also, WSDOT determined the duration of the thaw recovery as a function of the FI and TI (Equations 3 and 4). This study used environmental condition data and deflection testing data from Minnesota to verify the SLR guidelines developed my WSDOT and improve Minnesota's SLR procedure.

Objectives

The objectives of this research were to:

1. Develop improved predictive equations for estimating when to begin and end SLR.
2. Investigate changes in pavement strength in relation to freeze-thaw events.
3. Compare aggregate bases strength-recovery characteristics and assess their performance.

Methodology

The methodology used in this study to meet the objectives was to:

1. Compare WSDOT guidelines to Minnesota's past procedure for validity and ease of use.
2. Analyze environmental data from Mn/ROAD and other sites around Minnesota to determine the actual frost and thaw depth during spring-thaw.
3. Analyze deflection data from Mn/ROAD and determine the reduction in stiffness for the base and subgrade materials during spring-thaw.

Environmental Condition Data

Environmental data were compiled from Mn/ROAD and other statewide sites including air temperature, frost depth and subsurface temperature data. These data were analyzed to determine the dates on which the thaw began and ended. These dates were compared with the dates predicted from WSDOT's method. Also, the forecasted temperature data was analyzed to determine the precision and accuracy to supplement the prediction of when thaw begins.

Air Temperature Records

A historical analysis of air temperatures and FI for the past 30 years was performed using air temperature records from Mn/ROAD and several weather stations located near SLR zone boundaries. The weather stations used in this analysis were Becker, Buffalo, Grand Rapids, Minneapolis, Rosemount and Rochester. For each year of data, the following determinations were made: FI, date on which the TI = 15°C-days (25°F-days) is surpassed, and predicted thaw duration. This information was used to determine if reasonable relationships existed to determine the depth of frost or thaw in pavement structures using easily accessible average daily temperature data.

Forecasted and actual air temperature records were analyzed to determine the accuracy of the forecasted temperatures, if the forecasted temperatures improve in any way, and if there are any trends between the forecast and the actual temperature. From January 6 to January 31, 1999 and from February 1 to February 28, 1999, the actual temperatures along with 1, 2, 3, 4 and 5-day forecasted temperatures were recorded. This was done for the high and low temperature for each day. The following cities were chosen due to their geographic location in Minnesota, with Bemidji representing the northern zone, St. Cloud representing the central zone, Minneapolis representing the metro zone, and Worthington representing the southern zone.

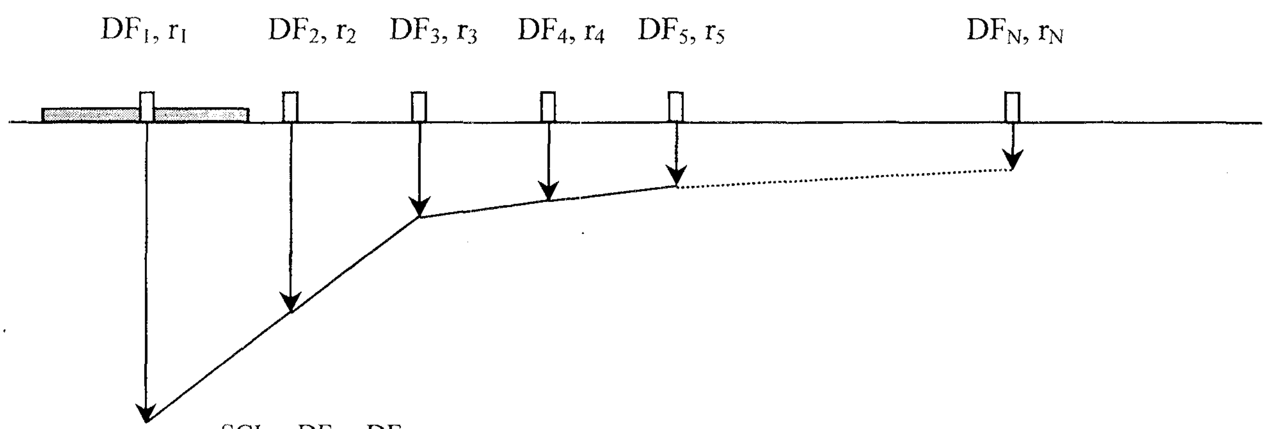
Frost and Temperature Sensor Data

The frost data were monitored using resistivity probes (RP) located at Mn/ROAD and other sites in Minnesota to determine the dates each year the thaw began and duration. A number of RP sensors were installed in flexible pavement sections around the state to provide a broader base and added verification of the Mn/ROAD observations. The RPs are constructed of 2.5 m (8.2 ft.) long PVC pipe with concentric pairs of copper conductor positioned every 50 mm (2 in.) along its length [25]. A significant increase in the measured resistance indicates frost.

The thermocouple sensors (TC) were also used at the Mn/ROAD facility (Figure 2). Mean daily pavement, base, and subgrade temperature data were compiled. These data were used to investigate relationships between air and pavement surface temperature and between pavement surface and base layer temperatures for improved thaw-begin predictions. The TCs were also used as an independent check on the observed RP thaw measurements. A complete discussion of these sensors and the installation procedures used at Mn/ROAD are given elsewhere [26, 27].

Deflection Testing

Deflection testing with an FWD was conducted on a regular basis at the Mn/ROAD facility to quantify the changes in flexible pavement strength during the spring-thaw period. Pavement deflection testing with the FWD typically commences in late February or early March and continues through late October. The distance of the FWD geophones relative to the center of the plate for the DF_1 through DF_7 sensors has generally been 0, 203, 305, 457, 610, 914, and 1524 mm (0, 8, 12, 18, 24, 36, 60 in.), respectively (Figure 4). A 300 mm (12 in.) diameter plate has been used.



$$SCI = DF_1 - DF_3$$

$$BDI = DF_3 - DF_5$$

$$AREA = \frac{1}{DF_1} \sum_{i=1}^{N} \left[(DF_i + DF_{i+1}) \bullet (r_{i+1} - r_i) \right]$$

Mn/ROAD FWD sensor configuration							
Sensor No.	1	2	3	4	5	6	7
Offset, mm	0	203	305	457	610	914	1254

Figure 4. FWD sensor configurations and deflection parameters.

Pavement layer moduli for test sections 25, 27, 28, 29 and 30 were estimated using the linear elastic backcalculation analysis software EVERCALC 5.11 [15]. This program has been found to provide good results with respect to predicted pavement response and reasonableness of predicted moduli [28]. The pavement structures were modeled as three-layer systems resting on a semi-infinite, fixed-modulus foundation [29].

An infrared thermometer located on the FWD testing trailer records pavement surface temperature. The surface and air temperatures were used to estimate the temperature at-depth using the BELLS2 procedure as described by Lukanen, et. al. [30]. An estimated subsurface temperature calculated using FWD data was used rather than the direct TC measurements due to the fact that a substantial amount of deflection data were collected prior to the time when the TC sensor datalogging equipment became fully operational. In order to utilize the early FWD data it was necessary to adopt a temperature estimation procedure. A direct measurement of subsurface pavement temperatures would be the best approach, however the estimated temperatures were found to compare reasonably well with the measured temperatures where TC data was available.

Pavement Strength Parameters

In addition to the moduli described above, several different deflection-based pavement strength parameters were investigated in this study to determine the changes in the pavement stiffness during the spring-thaw weakening period. They are: maximum deflection (DF_1), surface curvature index (SCI), base damage index (BDI), and basin area (AREA), (Table 4).

Table 4. Equations used for calculating FWD strength parameters.

Parameter	Year	Equation
SCI	1994 - present	DF_1 - DF_3
BDI	1994 - present	DF_3 - DF_5
AREA	1994 - 1995 (N=7) 1995 - 1996 (N=9)	$\sum_{i=1}^{N-1}\left[(DF_i + DF_{i+1})(r_{i+1} - r_i)\right]$

The deflection reading (DF_1) provides an indication of the overall pavement strength while the SCI and BDI provide information on changes in relative strength of the near-surface layers [7]. The SCI is calculated as the difference between the 0 and 305 mm (0 and 12 in.)-offset sensors (DF_1-DF_3) while the BDI is the difference between the 305 and 610 mm (12 and 24 in.)-offset sensors (DF_3-DF_5). There are various ways to calculate the basin AREA. The method used in this study was to determine the total area of the deflection basin using the trapezoidal rule and all sensors. That value was then divided by the DF_1 reading. Data from three drops at a target load level of 40 kN (9,000 lbs.) were used in this study and the data were linearly adjusted to a 40 kN (9,000 lbs.) reference load.

Temperature Dependency

In order to single out the seasonal effects on pavement deflections during FWD testing it is necessary to account for diurnal temperature changes since the stiffness of the HMA layer is temperature dependent. Various procedures have been proposed for adjusting measured pavement deflections to a constant reference temperature. Kim, et. al. [31], presented a procedure based on measured deflections and temperatures from test sites in North Carolina.

The approach taken in this study was to develop temperature adjustment curves based on measured deflection data from the Mn/ROAD test sections. The data used for the development of these relationships were obtained from special FWD tests where several points within each section were tested repeatedly over the course of a day to cover a range of temperatures. In this manner the effects of temperature can be accounted for during FWD testing. The slopes of each parameter (DF_1, SCI, BDI and AREA) plotted against the temperature were determined (Table 5). The curves for DF_1 and SCI are shown in Figure 5 and 6, respectively. All eight of the Mn/ROAD sections were found to display temperature dependent curves that were best represented by a non-linear relationship of the form:

$$f = a\,exp(bT) \tag{5}$$

where f = deflection parameter (μm or mm^2),

T = pavement temperature at mid-depth (°C), and

a and b = constants.

A regression analysis was performed on data from each individual test section; the resulting coefficients were then used to adjust the deflection parameter data. The form of the equation used to adjust deflection parameters to the reference temperature is:

$$f' = f\,exp[b(T'-T)] \tag{6}$$

where f' = adjusted parameter,

f = parameter measured with FWD,

b = experimentally determined slope,

T = pavement temperature at mid-depth, and

T' = reference temperature of 20 °C (68°F).

Table 5. Results of regression analyses of temperature dependency effects on FWD strength parameters.

Test Section	Slope (b) of Temperature Curve For Parameter Indicated[a]		
	DF_1	AREA	SCI
24	0.0082	-0.0065	0.0185
25	0.0142	-0.0095	0.0303
26	0.0360	-0.0156	0.0571
27	0.0185	-0.0070	0.0215
28	0.0085	-0.0052	0.0163
29	0.0231	-0.0119	0.0385
30	0.0214	-0.0111	0.0369
31	0.0099	-0.0064	0.0191

[a]Slopes are based on non-linear model f = a*exp*(bT).

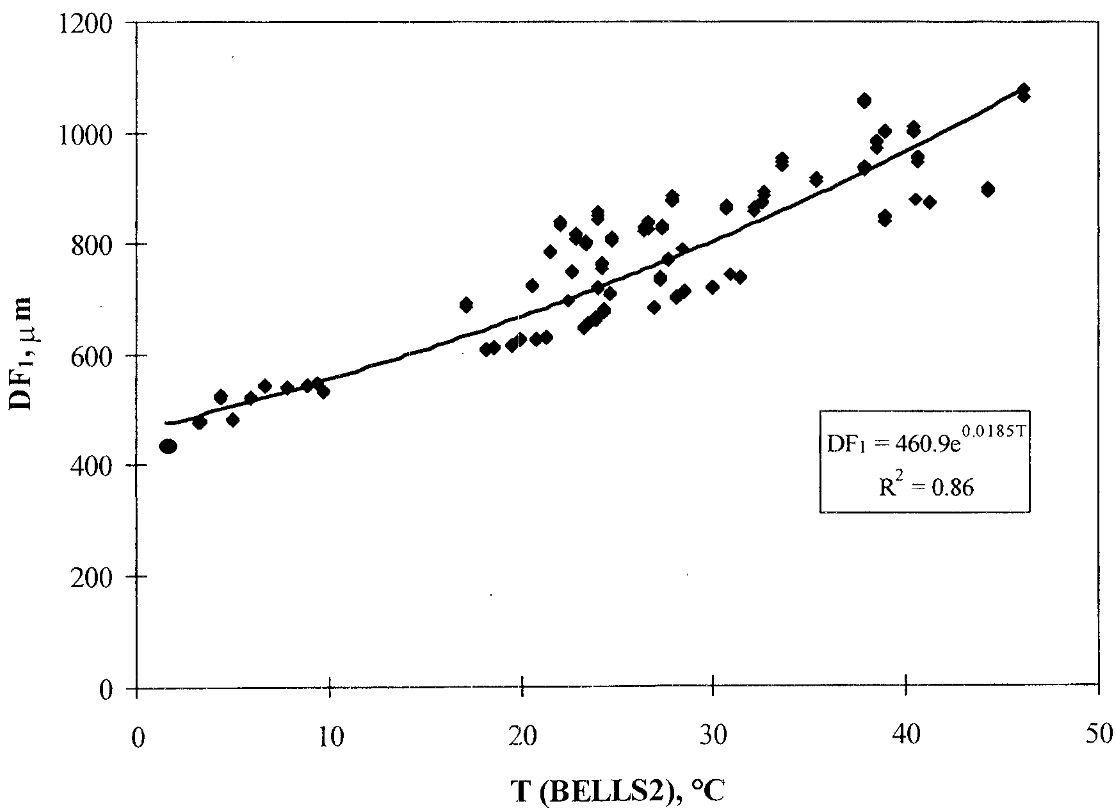


Figure 5. FWD deflection (DF_1) vs. pavement temperature (BELLS2), Mn/ROAD test section 27, 1994-95, deflections adjusted to 40 kN load, BELLS2 procedure.

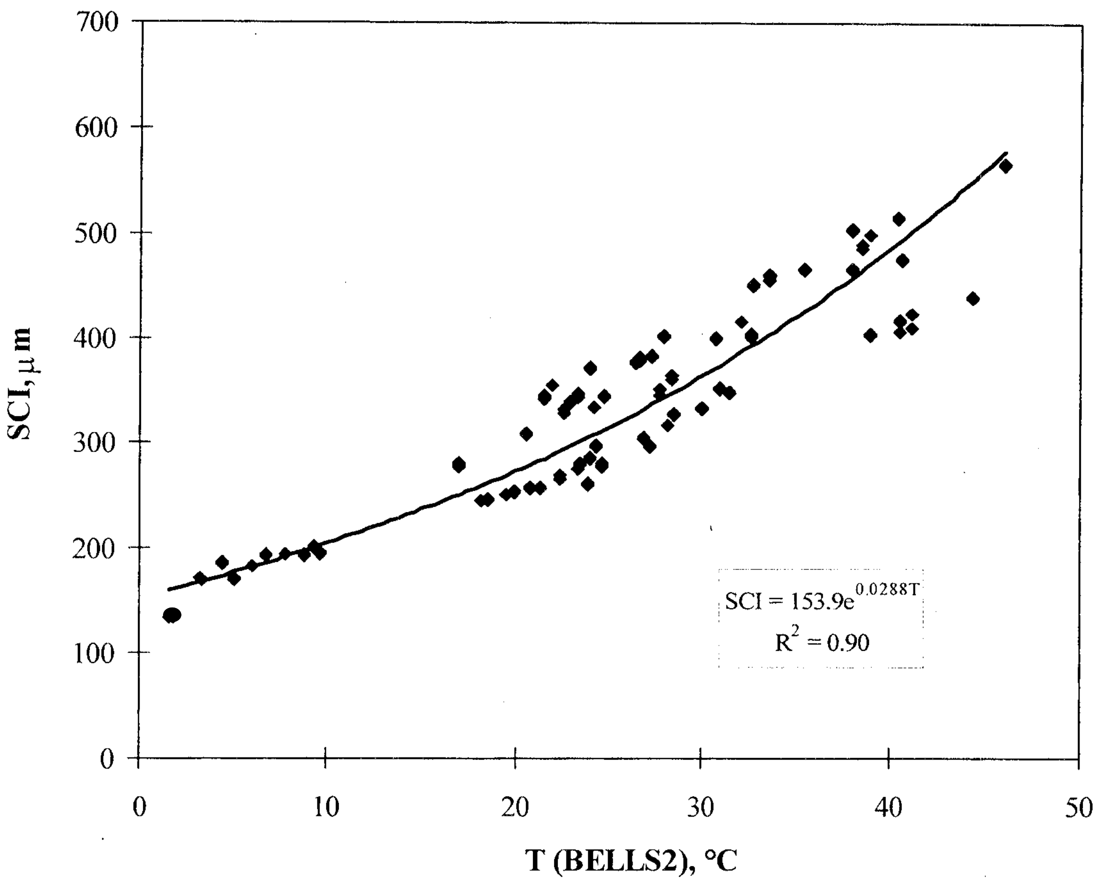


Figure 6. FWD SCI vs. pavement temperature (BELLS2), Mn/ROAD test section 27, 1994-95, deflections adjusted to 40 kN reference load, BELLS2 procedure.

Summary

In summary, the research approach taken in this study used environmental condition data and deflection testing data from Minnesota to verify the SLR guidelines developed by WSDOT [11, 12] and improve Minnesota's SLR procedure. The past SLR placement dates were compared to the dates predicted using WSDOT's method. These dates were also compared to frost and thaw depth data from Mn/ROAD and other sites located in Minnesota determined from environmental sensors. Finally, the recovery rate of various base layer materials were compared using deflection data. The results from these analyses are discussed in the next chapter.

CHAPTER FOUR

RESULTS

Introduction

This chapter presents the results used to improve Minnesota's SLR policy. The SLR procedure developed by WSDOT [11, 12] was applied and adjusted to Minnesota conditions and proved to be a simple and accurate method of predicting when to begin SLR in Minnesota. Revisions were made to the SLR procedure to better predict the beginning of the thaw period for Minnesota using historical SLR data, average daily air temperature, surface and subsurface temperatures, and deflection data.

Using the FI and TI data and the observed thaw duration, Equations 3 and 4 were evaluated for the prediction of the thawing duration and SLR period in Minnesota. A revised equation was developed to more accurately predict the thaw duration for Minnesota conditions, however the coefficient of determination (R^2) was fairly low.

Finally, the rate of strength recovery of the base layer materials at Mn/ROAD were investigated using moduli backcalculated from FWD deflection data. Several consistent trends were noted between the type of base material, the deflection parameters and the recovery rate of the material. It was determined that it typically takes 8 weeks for pavement base layer to recover from the spring-thaw in Minnesota, and therefore the duration of SLR is fixed at 8 weeks in the new SLR policy.

Results of Historical FI Calculations

The historical FI data was analyzed for Minnesota to quantify the harshness of a typical winter. As expected, the calculated FI showed that the climatic variation in Minnesota can be extreme. The past 30-year period of average daily temperatures showed that the average yearly FI ranged from 1600°C-days (2880°F-days) in the north to 900°C-days (1620°F-days) in the south. Extreme winters have been as high as 2100°C-days (3780°F-days) in the north. FI values for the Mn/ROAD site (located in the central zone) have ranged from 900 to 1300°C-days (1620 to 2340°F-days) between 1993 and 1997. The mean yearly air temperature can vary from 3.5°C (38.3°F) in the north to 7°C (44.6°F) in the south.

Comparison Between Actual and Forecasted Air Temperature

The forecast temperatures do not seem to have any consistent pattern. For any particular day and city there can be a difference from 0.5 to 10.5°C (1 to 20°F) from the actual temperature, but the forecasts are typically off by 2 to 4.5°C (4 to 8°F). There is little if any improvement as the forecast is nearer to the actual day. This implies that a five-day forecast is about as accurate or inaccurate as the other forecasts. Therefore, the forecasts are probably useful for predicting the trend, but not the actual date or extent of the thaw. Also, the forecast for a given city is consistently slightly high or low when the data from the entire month are averaged. This suggest a systematic error in the forecast model or interpolation done with the model results. Therefore, it is appropriate to use several cities in a given zone to better predict the beginning thaw date of the zone. Finally, there does not appear to be any consistent difference in the accuracy of the January forecasts compared to the February forecasts. Therefore, it is appropriate to assume that the forecast accuracy does not change significantly during the spring thaw period.

Results of Load Restriction Analysis

The historical placement and removal dates of SLR for Minnesota compared reasonably well to the dates predicted using WSDOT's method, however some adjustments to the procedure were needed. The average and standard deviation of the placement and removal dates and length of the SLR period for the various frost zones are summarized in Table 6. The average and standard deviation of the TI at the time of load restriction placement are also shown in Table 6. Next, the difference between the actual Mn/DOT dates and the predicted placement and removal dates were computed. The average and standard deviation of these differences for the three frost zones that were analyzed are shown in Table 7.

Table 6. Average SLR placement and removal dates (1986 - 1996) in Minnesota.

Zone	Placement		Removal		SLR Period, days		TI[a], °C-days (°F-days)	
	AVE.	S.D.	AVE.	S.D.	AVE.	S.D.	AVE.	S.D.
North	18-Mar	9	17-May	6	58	7	33 (59)	22 (40)
Central	14-Mar	8	9-May	8	56	6	48 (87)	33 (59)
Metro	11-Mar	7	29-Apr	8	48	8	-	-
South	9-Mar	9	8-May	7	60	5	-	-
South East	10-Mar	9	10-May	7	60	6	44 (79)	26 (47)

[a]TI values are from dates on which load restrictions were placed using Equation 1.

Table 7. Summary of differences in load restriction placement and removal dates between Mn/DOT practice (1986 - 1996) and WSDOT predictions.

Zone	Difference in Placement Date, Days				Difference in Removal Date, Days			
	Should[a]		Must[a]		D = 25+0.018(FI)[b]		TI = 0.3(FI)[b]	
	Avg.	SD	Avg.	SD	Avg.	SD	Avg.	SD
North	1	7	-5	8	12	12	2	7
Central	4	6	0	7	20	5	20	6
South East	1	7	-3	8	20	6	16	4

[a]The dates for "SHOULD" and "MUST" levels correspond to the dates after which thawing indexes of 15 and 30 °C-days, respectively, were surpassed.
[b]Use °C-days in equations 3 and 4.

It is shown that for the North, Central and South East Zones, SLR were placed between the should and must levels suggested by WSDOT, Table 7. For example, in the North Zone, the average placement date is March 18 and the average duration is 58 days, Table 6. Using Equation 1 and historical average daily air temperature data, it was calculated that the average TI is 33°C-days (60°F-days) when the restrictions were placed, which corresponds well with WSDOT's predicted date that SLR must be placed (about 25°C-days (50°F-days)). However, the length of the SLR period suggested by WSDOT's method did not correspond as well since the predicted period was on average 2 to 20 days longer than the actual period. This warranted further research, thus another equation was investigated and documented later in this chapter.

Similar results were seen when comparing WSDOT's method to weather station data from Mn/ROAD for 1994, 1995, 1996 and 1997 spring-thaw events. As can be seen from Table 8, the date for removal of restrictions based on the TI and the FI (Equation 4) is later than that based upon the FI alone (Equation 3). The two dates shown for the 1995-96 season are based on two different possible times that thaw initiation could have taken place.

Table 8. Summary of load restriction placement and removal dates for Mn/ROAD site.

Year	FI, °C-days	Placement Date[a]		Removal Date	
		Should	Must	D = 25+0.018(FI)	TI = 0.3(FI)
93-94	1200	5-Mar	14-Mar	11-Apr	13-May
94-95	905	12-Mar	13-Mar	15-Apr	30-Apr
95-96	1340	13-Mar	17-Mar	20-Apr	20-May
	1415	10-Apr	12-Apr	19-Apr	21-May

[a]The dates for "SHOULD" and "MUST" levels correspond to the dates after which thawing indexes of 15 and 30 °C-days were surpassed.

Comparison of Predicted and Actual Critical Thaw Depths

Environmental sensor and deflection data from Mn/ROAD were analyzed to determine the actual dates and duration that the pavement structures thawed between 1994 and 1997. The data included frost depth measured by resistivity probes (RP), temperature measured by thermocouples (TC), and deflection measurements from FWD testing. The results of the analysis between base layer temperature, asphalt layer temperature and air temperature were used to determine the actual thaw duration and to determine if correlations exist between the use of FI and TI to predict when to place and remove SLR for Minnesota.

The prediction model of the thaw duration that was developed by WSDOT was compared to the observed thaw duration at Mn/ROAD as determined from RP sensors for each particular year, Figure 7. It is shown that the predicted thaw duration does not accurately correspond with the actual duration. One possible reason for this deviation may be explained by the fact that the WSDOT equations were developed from numerical modeling simulations. Such a model may be useful for studying the relative effects of the various parameters but may not truly represent actual field conditions and variability.

Rapid thawing durations have been observed for TS 24 and TS 25, which are constructed on granular subgrade. Because of this, and also due to the fact that SLR is less of an issue for highways with granular subgrades, these two sections are excluded from Figure 7.

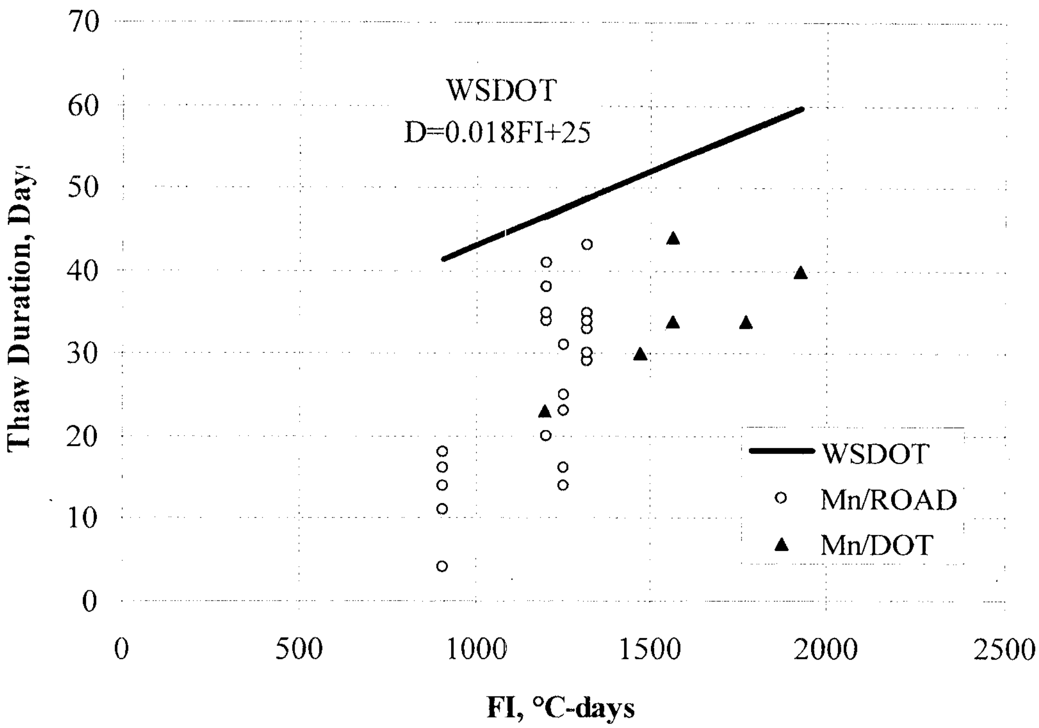


Figure 7. Observed and predicted thaw duration vs. FI.

A typical frost-depth curve is shown in Figure 8. The data are from a RP located in the right, outer wheel path (OWP) of TS 30, in which the probe's shallowest reading is 305 mm (12 in.) below the pavement surface. During the spring of 1996, several thawing and re-freezing events occurred, a fairly common occurrence in Minnesota that complicates the SLR decision process. A graph of the TI for the 1996 spring season is shown in Figure 9. From Figure 9 it is apparent that a three-day long warming period began on February 7. Placement of SLR may have been premature at this point, however the initial event on February 7 did trigger some thawing.

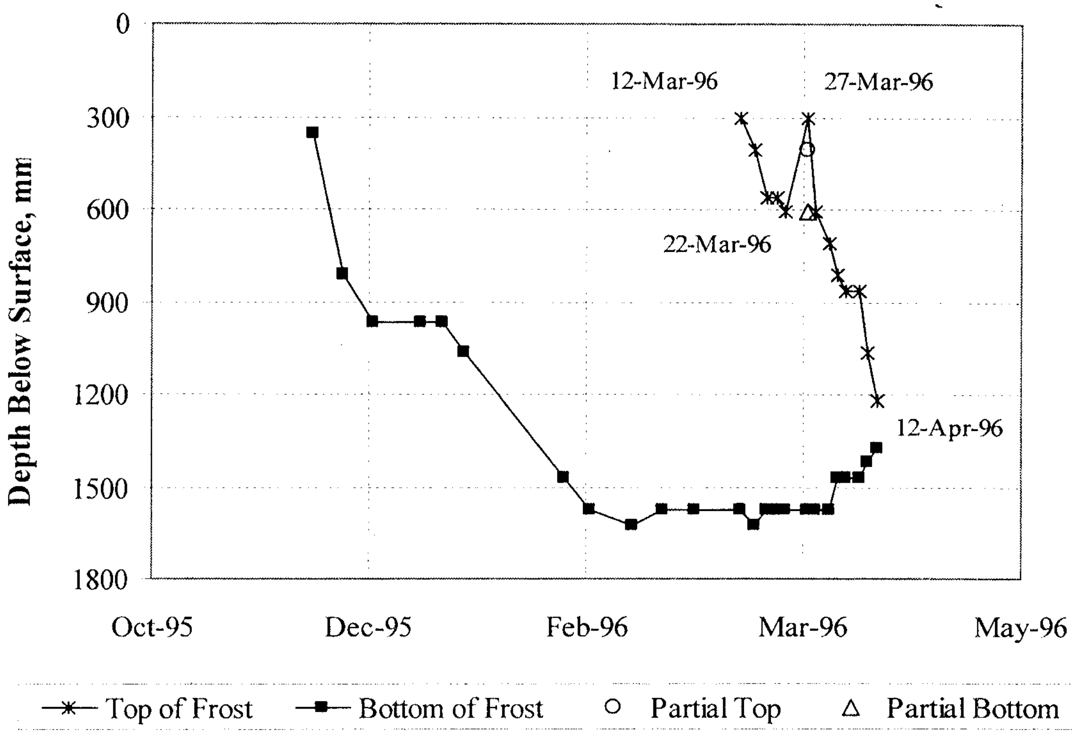


Figure 8. Frost profile from resistivity probe measurements, Mn/ROAD test section 30, 1995 - 1996.

Figure 9 shows that the TI calculated with a fixed reference temperature equal to -1.7°C (29°F) surpasses the should level on March 13, and surpasses the must level April 10. However, Figure 8 shows that significant thawing occurs after March 12. Thus the TI with a reference temperature equal to -1.7°C (29°F) did not accurately determine when thaw occurs.

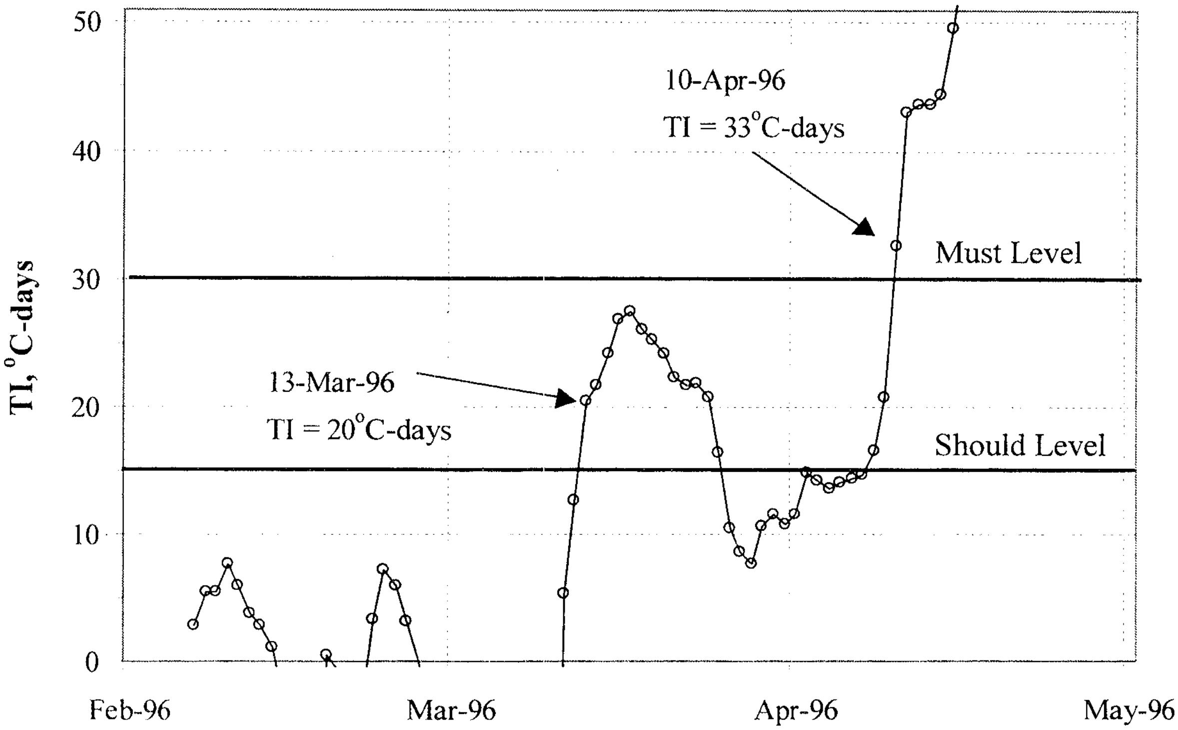


Figure 9. Thawing index history for spring 1996.

The frost depth data from the six flexible test sections were analyzed to determine the beginning and ending dates of the thaw period. Table 9 summarizes the frost highlights from the spring-thaw periods in 1994, 1995 and 1996 at Mn/ROAD; these data are from the RP arrays located in the right, outer wheelpath of the inside lane. It is evident that the thaw in the pavement sections with sandy subgrades (TS 24 and 25) was out sooner than those with clay subgrades. When comparing Tables 8 and 9, it can be seen that the thaw began at the Mn/ROAD test sections prior to the placement of SLR for the central zone.

Table 9. Summary of spring freeze-thaw events from resistivity probe readings.

Test Section	1993 - 94		1994 - 95		1995 - 96	
24	Thaw starts	8-Mar	Thaw starts	12-Mar	Thaw starts	23-Feb
					Part. freeze	1-Mar
					Thaw	12-Mar
	Frost out	25-Mar	Frost out	17-Mar	Frost out	29-Mar
25	Thaw starts	8-Mar	Thaw starts	12-Mar	Thaw starts	23-Feb
					Part. freeze	1-Mar
					Thaw	12-Mar
	Frost out	16-Apr	Frost out	22-Mar	Frost out	19-Apr
26	Thaw starts	8-Mar	Thaw starts	12-Mar	Thaw starts	12-Mar
					Part. freeze	27-Mar
					Thaw	29-Mar
	Frost out	12-Apr	Frost out	27-Mar	Frost out	15-Apr
27	Thaw starts	7-Mar	Thaw starts	13-Mar	Thaw starts	12-Mar
					Part. freeze	27-Mar
					Thaw	29-Mar
	Frost out	12-Apr	Frost out	27-Mar	Frost out	19-Apr
28	N/A	N/A	N/A	N/A	N/A	N/A
29	N/A	N/A	N/A	N/A	N/A	N/A
30	Thaw starts	8-Mar	Thaw starts	13-Mar	Thaw starts	15-Mar
					Part. freeze	27-Mar
					Thaw	29-Mar
	Frost out	9-Apr	Frost out	27-Mar	Frost out	15-Apr
31	Thaw starts	6-Mar	Thaw starts	13-Mar	Thaw starts	15-Mar
					Part. freeze	27-Mar
					Thaw	29-Mar
	Frost out	9-Apr	Frost out	27-Mar	Frost out	17-Apr

The deflection data support these observations. Deflections for lanes 1 and 7 are shown in Figure 10 for spring 1996 and are superimposed over the frost-depth curve. The first round of testing occurred on March 15 when lane 7 was tested; lane 6 was subsequently tested on March 16. Both these lanes showed increased deflections the next time they were tested one week later on March 22 and March 23. The next testing round occurred on March 28 and March 29 and all the sections displayed a dramatic reduction in deflection. Recall that the RP readings taken between February 16 and March 22 indicated that TS 25 and 27 were partially thawed and that on March 27 partially frozen conditions were observed. The low deflections obtained on March

22 and March 23 were due to semi-frozen conditions. Figure 10 also shows that the deflections significantly increase when the pavement thawed between 300 and 600 mm (12 and 24 in.). Thus, the critical placement of SLR is when the thaw has reached this depth.

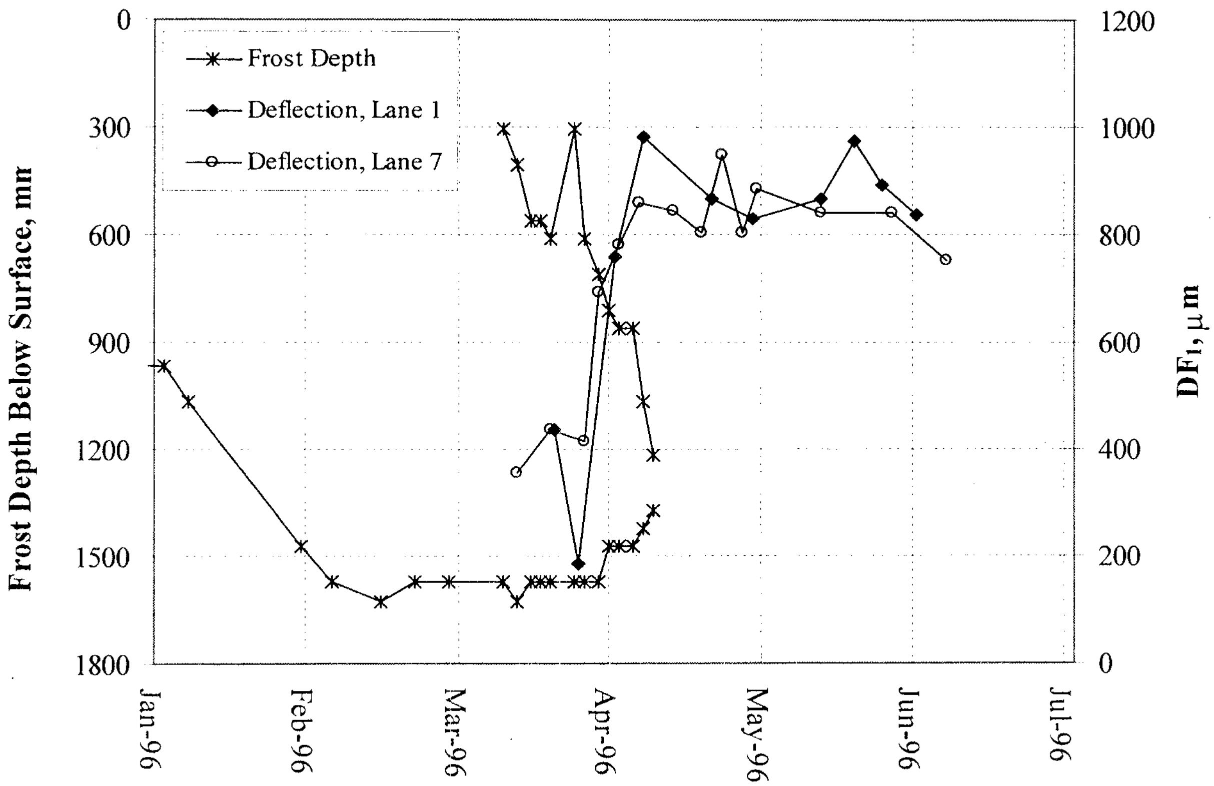


Figure 10. Frost profile and deflection changes.

Analyses of Air, Surface and Subsurface Temperatures Results

The spring (January through April) base and asphalt TC temperatures for all eight test sections from 1995 to 1997 were analyzed. TC sensors from the top of the base were selected for this analysis and the mean of all TC sensors in the HMA layer were used. For each section the mean daily base temperature was plotted against the asphalt temperature. Data from all sections and years yielded nearly straight lines with only slight scatter and similar slopes that passed very close to the origin. Therefore it can be concluded that during the spring, the base and asphalt temperatures are near 0°C (32°F) at roughly the same time. These results agree with findings by other researchers [13, 23].

A similar analysis was done for the mean daily air and asphalt temperatures. For each section the mean daily air temperature was plotted against the asphalt temperature. Regression analyses of these data were performed and yielded horizontal intercepts of approximately -5°C (23°F). This suggests that when the entire spring period is averaged together, the asphalt temperature is 0°C (32°F) when the air temperature is -5°C (23°F). Furthermore, based on the results of the comparison between base and asphalt temperatures, it is reasoned that the mean air temperature at which thawing in the base may begin to occur (T_{ref}) is about -5°C (23°F). While this value is fairly close to the T_{ref} = -1.7°C (29°F) suggested by others, it was different enough to warrant further investigation.

A graph of HMA and base layer temperature changes is shown in Figure 11 for the spring of 1997 and TS 28 with the TI for the period. The date corresponding to a TI (T_{ref} = -1.7°C) of 15°C-days (25°F-days) is shown by the arrow. Note that temperatures within the asphalt and base layers surpass 0°C (32°F) several weeks prior to this date. It is clear from this graph that significant warming and thawing took place prior to the predicted thaw-begin date attained on March 25. The FWD data support this observation in that a substantial increase in deflection occurred prior to the predicted thaw-begin date (Figure 12).

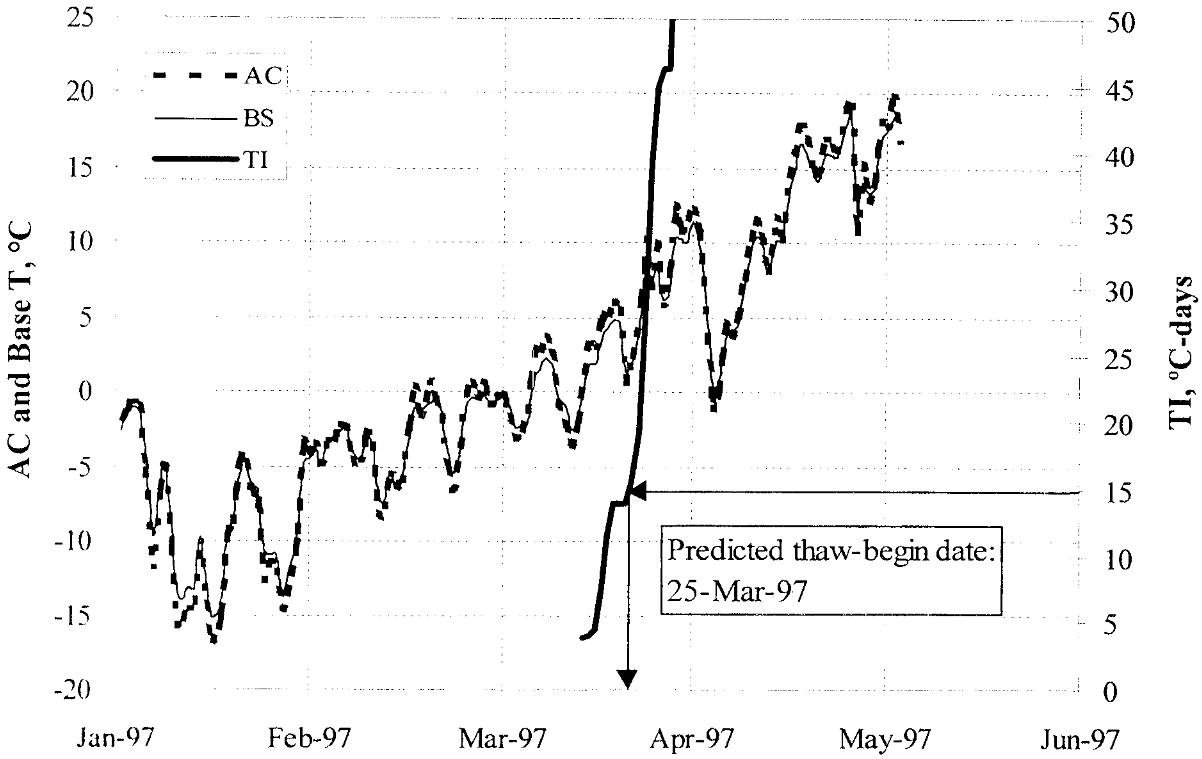


Figure 11. Variation in AC and base temperature with Thawing Index, Mn/ROAD test section 28, 1997.

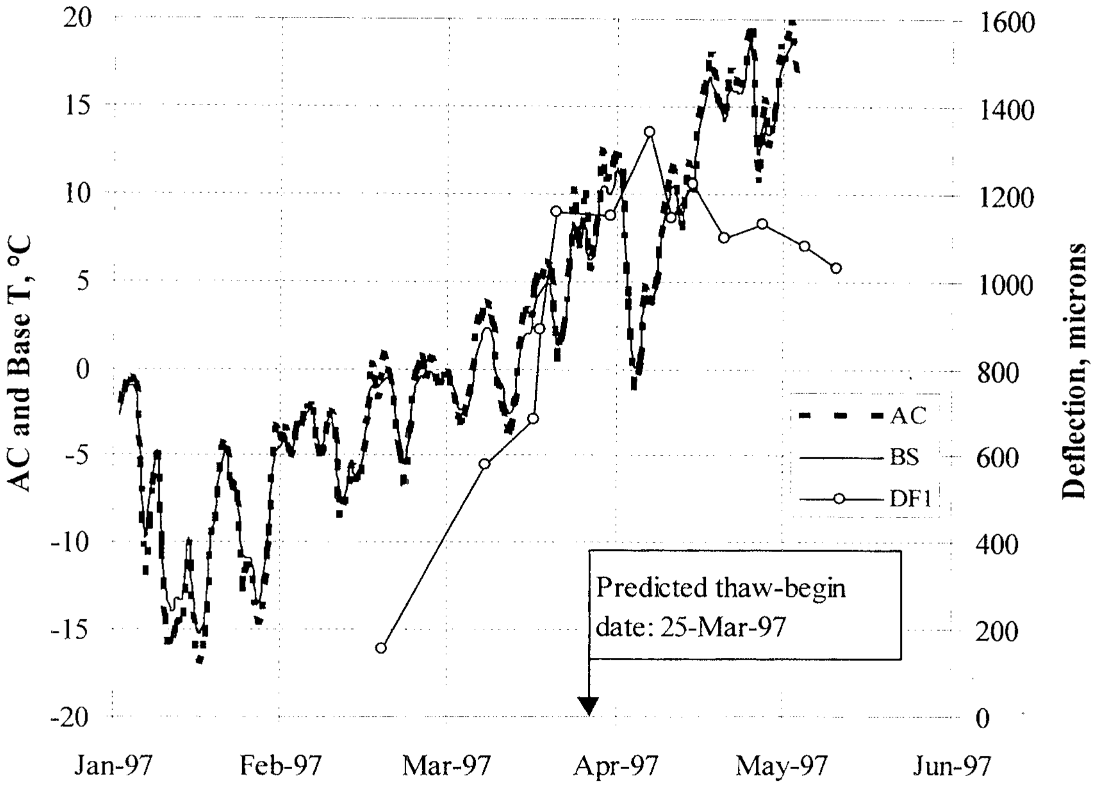


Figure 12. Variation in AC and base temperature with deflection, Mn/ROAD test section 28 deflections adjusted to 40 kN load and 20 °C, 1997.

Variable Reference Temperature

The results of the temperature analysis showed that a new T_{ref} was needed to determine when to place SLR in Minnesota. To investigate the changes in the T_{ref} during the early spring season (January through March) it was decided to break the temperature analysis down by month. Mean monthly air temperatures for 1994-97 were analyzed given the constraint that the asphalt temperature was 0 ± 0.56°C (32 ± 1°F). The results showed the mean spring air temperatures to vary from -0.9, -2.3, and -4.3°C (30.4, 27.9, and 24.3°F) for the months of January, February, and March, respectively. Thus, the air temperature required for thawing actually decreases from January to March due to the increase in the declination of the sun during the spring.

The new predicted thaw-begin dates were not much different than the observed ones based on RP data. For the spring of 1997, the new method predicted a thaw-begin date of March 19 as opposed to March 25 as determined previously, Figure 13. It appears that the reference temperature and threshold level described above have the advantage of being able to detect thaw in the event of erratic air temperature warming trends. Thus, a variable T_{ref} for TI is used to calculate the TI in the new SLR policy.

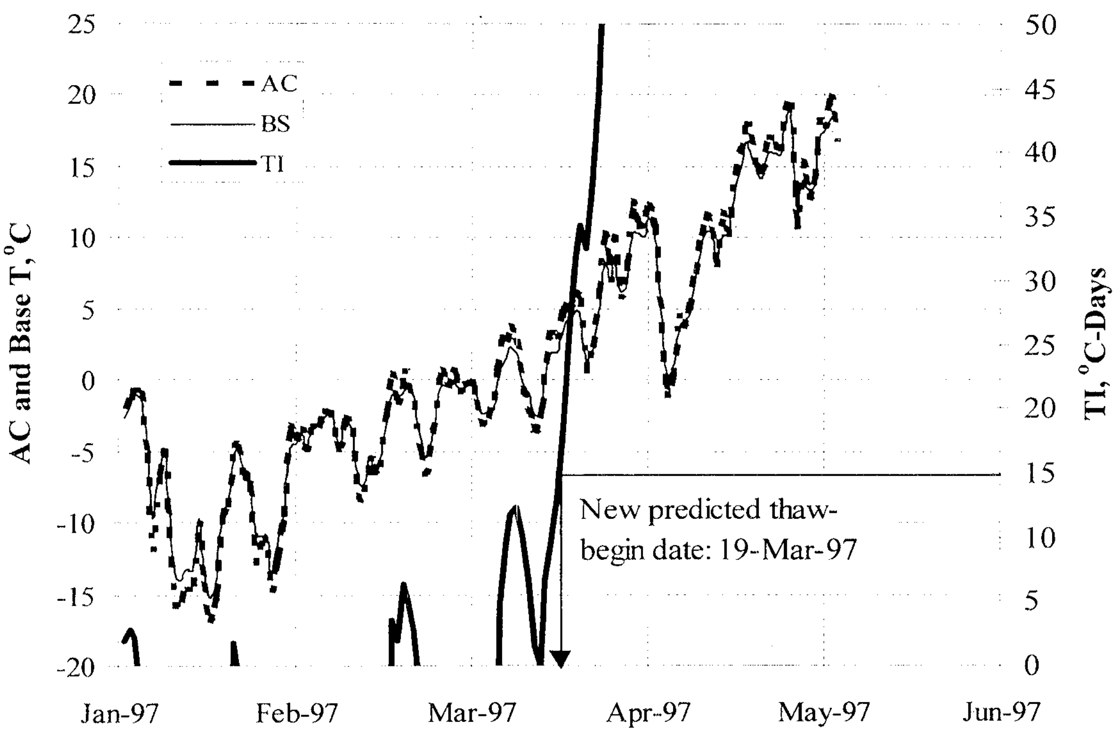


Figure 13. Variation in HMA and base temperature with *modified* Thawing Index.

Improved Prediction of Thaw Duration

An improved thaw duration (D) prediction relationship was investigated. In order to include the effects of frost depth, the actual measured frost penetration was incorporated into the regression analysis. In order to model the observations accurately it is necessary to include an interaction term. Even though the regression has an R^2=0.50, Equation 7 predicts D better than Equation 3 (Figure 14). The analysis resulted in the following equation:

$$D = 0.15 + 0.010FI + 19.1P - 12090 * \frac{P}{FI} \qquad (7)$$

where: $R^2 = 0.50$,

SEE = Standard Error of Estimate = 8 days,

P = frost depth (m).

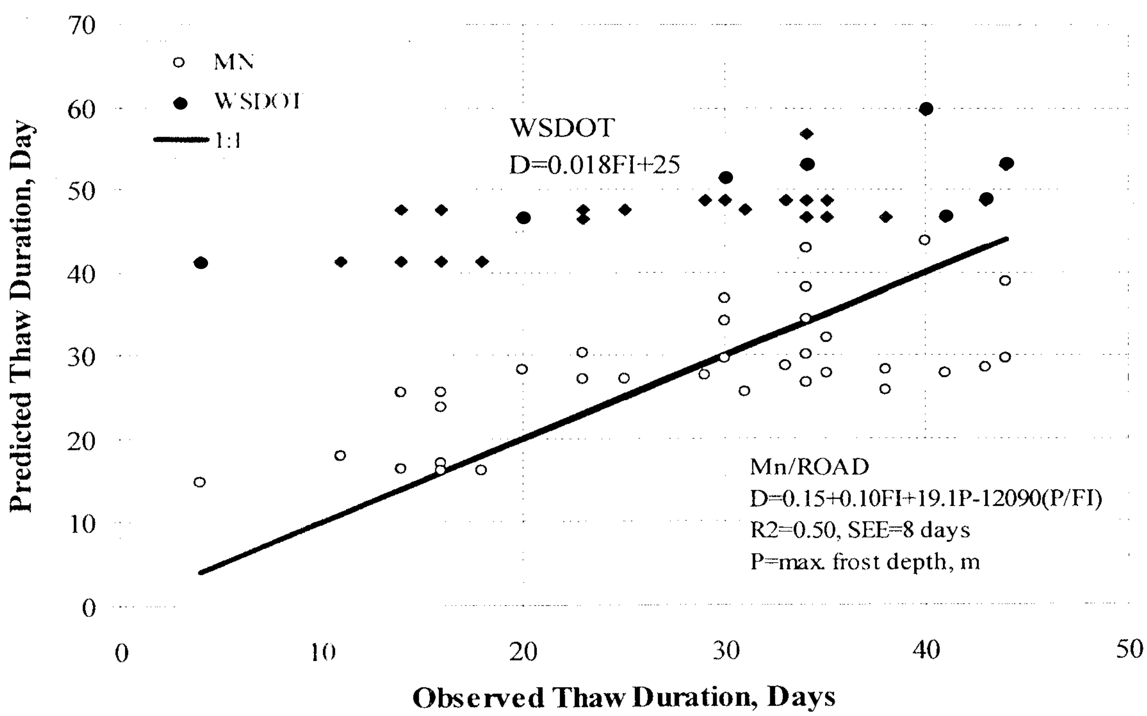


Figure 14. Comparison of observed and predicted thaw durations using new equation.

An analysis of frost depth predictions was also made. Chisholm and Phang developed an equation that can be used to predict the maximum frost depth based on air FI [32]:

$$P = -0.328 + 0.0578\sqrt{FI} \qquad (8)$$

The use of an estimated frost depth based on Equation 6 as input to Equation 5 was investigated. The prediction error did not increase significantly relative to the observed durations. This means that, in the absence of actual measured frost depth data, an estimate from Equation 8 can be used as input to Equation 7. Due to the relatively low correlation between the duration predicted using Equation 7 and the actual duration, Minnesota has implemented a fixed 8 week SLR period. This is the typical duration of the pavement structure recovery period, and is discussed in the next section.

Base Layer Material Recovery Results

The results from this study were used to compare the spring-thaw recovery rates for different base materials used in the pavement sections at Mn/ROAD. For these analyses, the deflection parameters were adjusted to reference conditions. The results showed that the pavement structures with a sandy subgrade recovered significantly faster than those with clayey subgrades. The typical duration of the base recovery period for clayey subgrades was 8 weeks.

The measured deflections were used to calculate the deflection parameters defined earlier, and the moduli to compare to the date on which frost was observed to leave the ground. On average, all the maximum responses analyzed in this study occurred within 7 to 10 days either side of the thaw completion date. The next section discusses the results from TS 26, 27, 28, 29, 30 and 31, which are constructed on the silty-clay subgrade. For TS 24 and 25 that were constructed on a sand subgrade, there did not appear to be a significant peak in any of the deflection parameters except for the AREA, as shown in Table 10.

Table 10. Ratio of late season to minimum spring value for deflection, area, and subgrade moduli.

		1993 - 94		1994 - 95		1995 - 96[a]	
Test Section	Parameter	355 kN[b]	455 kN[b]	355 kN	455 kN	355 kN	455 kN
24	DF_1	1.07	1.06	1.02	1.05	1.00	0.96
	AREA	1.09	1.15	1.01	1.10	0.96	1.01
	E_{SG}	0.94	0.90	0.97	0.91	1.01	1.17
25	DF_1	1.01	1.03	1.18	1.07	1.01	0.94
	AREA	1.04	1.14	1.06	1.12	0.93	0.98
	E_{SG}	0.97	0.86	1.19	1.03	1.19	1.12
26	DF_1	0.77	0.74	1.13	0.72	1.05	0.79
	AREA	0.69	0.73	0.87	0.87	1.00	0.81
	E_{SG}	1.51	0.91	2.24	2.17	1.24	0.97
27	DF_1	0.62	0.79	0.71	0.80	0.86	0.89
	AREA	0.67	0.73	0.75	0.79	0.92	0.83
	E_{SG}	1.54	1.17	1.48	1.52	1.11	1.41
28	DF_1	0.78	0.78	0.87	0.73	0.85	0.80
	AREA	0.74	0.74	0.83	0.71	0.93	0.83
	E_{SG}	1.28	1.34	1.16	1.31	0.97	1.12
29	DF_1	0.88	0.87	0.74	0.91	0.78	1.85
	AREA	0.78	0.80	0.90	1.00	0.95	0.95
	E_{SG}	1.25	1.26	1.35	1.26	1.18	0.87
30	DF_1	0.71	0.94	0.90	1.02	1.14	1.11
	AREA	0.75	0.87	0.89	0.90	1.07	1.02
	E_{SG}	1.28	1.19	1.24	1.22	1.08	1.12
31	DF_1	0.83	0.83	0.87	0.71	0.80	0.81
	AREA	0.79	0.78	0.79	0.78	0.83	0.80
	E_{SG}	1.34	1.39	1.31	1.35	1.21	1.31

[a]Data from 1995-96 season are only current through 5-Jun-96.
[b]355 and 455 kN denote gross test truck weights on normal and overweight lanes on the Mn/ROAD low-volume road test facility.

FWD and Strain Data Results

During spring 1994, a series of FWD tests were conducted in which in situ pavement strain gages were tested several times over a six week period during the spring thaw. These sensors were asphalt strain gages mounted at the bottom of the HMA layers. In these tests the FWD was positioned directly over the center of each strain gage. Both longitudinally and transversally-oriented strain gages were tested. The strain gage response histories were analyzed to determine the maximum strain value. From these tests a relationship between SCI and measured strain was developed and is shown in Figure 15. This demonstrates that the strain near the bottom of the surface HMA layers can be well represented by the SCI calculated using FWD deflections.

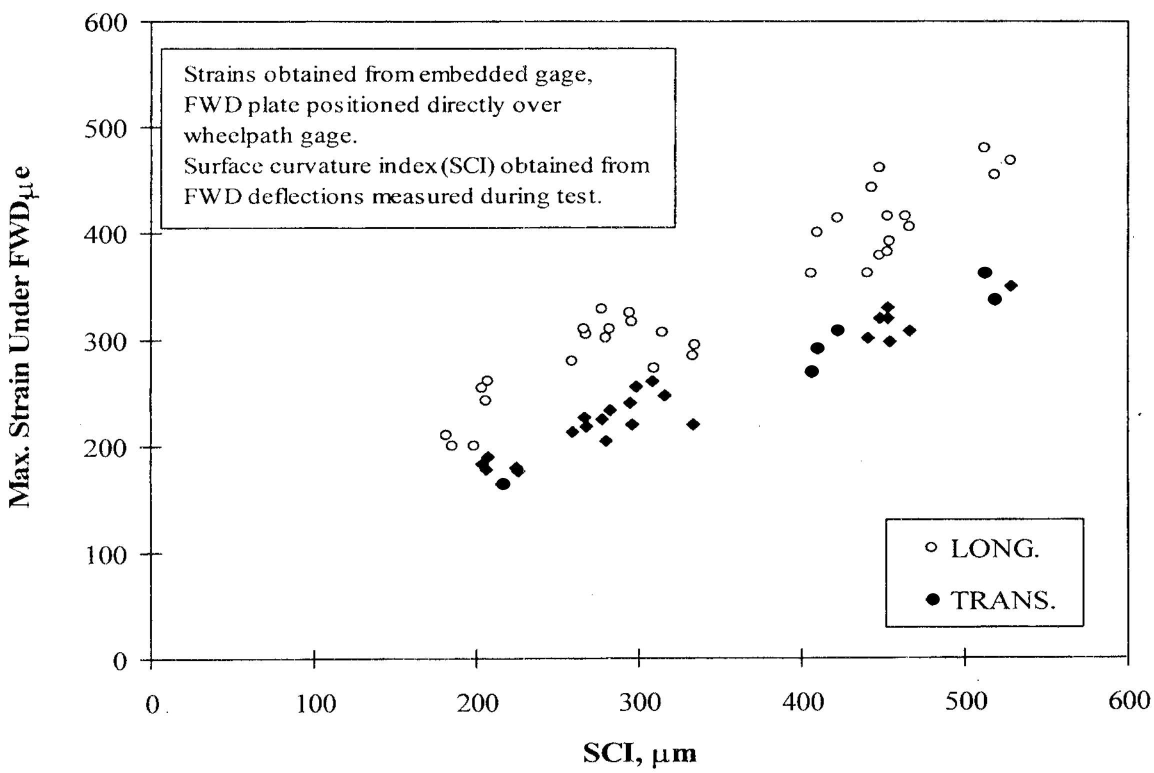


Figure 15. Peak measured strains from in situ sensor vs. FWD SCI, Mn/ROAD test section 27, spring 1994, 40 kN reference load.

Deflection Parameter Results

A typical seasonal variation in DF_1 and SCI for TS 27 are shown in Figures 16 and 17, respectively. As can be seen from these figures, there is a noticeable spring peak with subsequent recovery. For all the test sections, the seasonal variation curves for each parameter were analyzed to determine the maximum spring response. Table 11 gives the approximate dates associated with the maximum and minimum deflection parameters. It should be noted that, in many cases, peaks do occur at later times in the year. These are likely due to short-term effects from rainfall. The maximum and minimum values that are reported in this study are those observed during the spring period only.

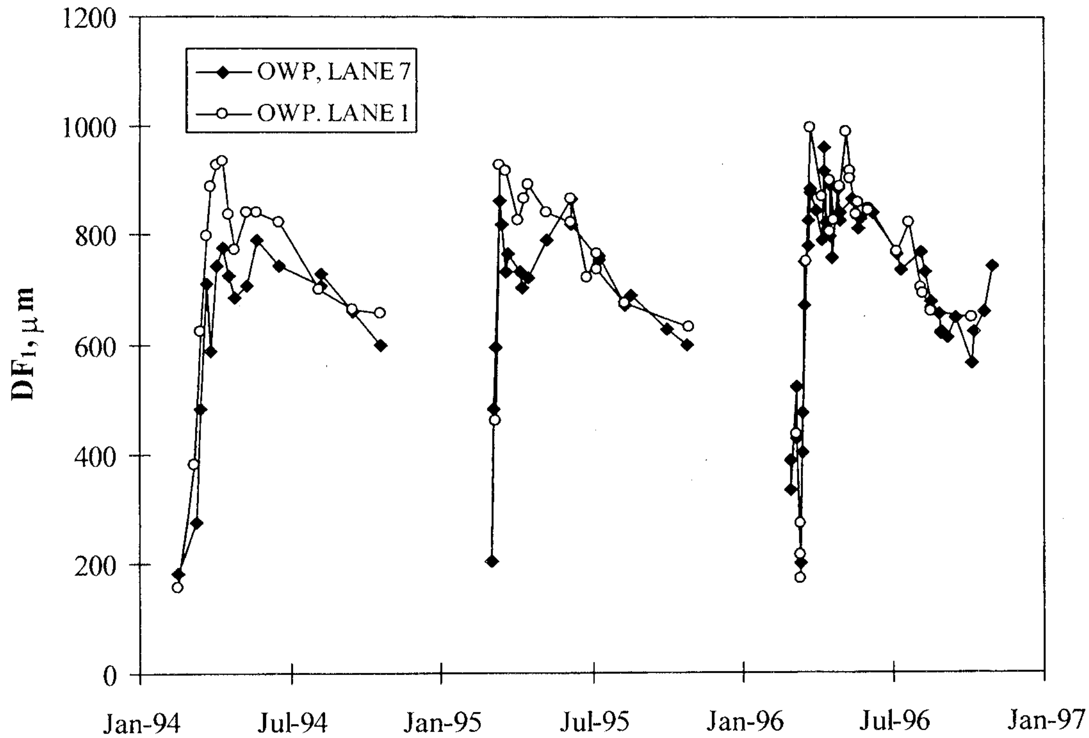


Figure 16. Seasonal changes in temperature adjusted FWD deflection, Mn/ROAD test section 27, 1994-96, 40 kN reference load, 20°C reference temperature.

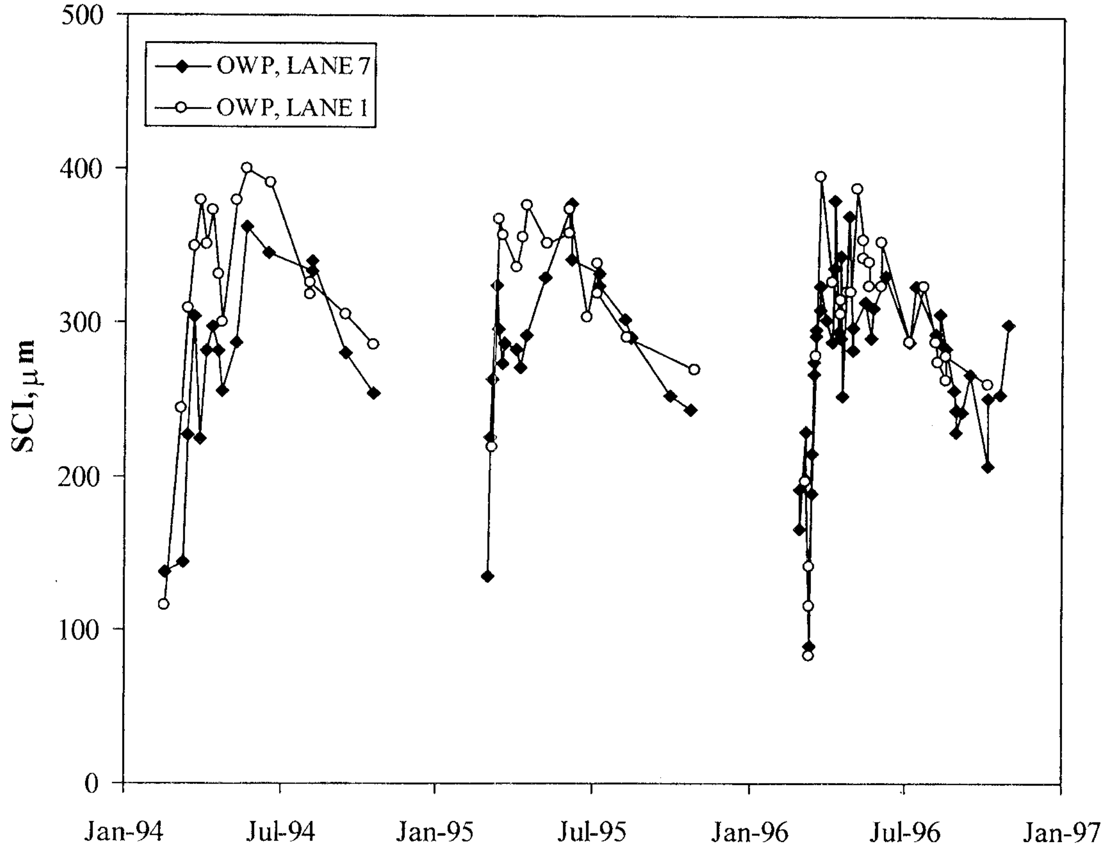


Figure 17. Seasonal changes in temperature adjusted FWD SCI, Mn/ROAD test section 27, 1994 - 1996, 40 kN reference load, 20°C reference temperature.

Table 11. Dates of maximum and minimum spring deflection parameters.

Parameter[a]	1993-94	1994-95	1995-96
DF_1	10-Apr	5-Apr	15-Apr
AREA	12-Apr	1-Apr	16-Apr
SCI	16-Apr	10-Apr	15-Apr
BDI	8-Apr	26-Mar	15-Apr
E_{SG}	8-Apr	26-Mar	15-Apr

[a]Data shown are for test sections with fine-grained subgrade and RP sensors that are routinely monitored (test sections 26, 27, 30 and 31).

For all sections the SCI tends to peak later than the other parameters with the full-depth section (TS 26) peaking later in the summer. The largest time lags observed were for the two sections on Cl. 3 Sp. base or subbase (TS 30 and 31). Recall that the Cl. 3 Sp. material has over

10 percent more fines than the other base/subbase materials. Overall, the BDI and DF_1 tend to peak at about the same time. In addition, the sections with peak dates closest to the end-of-thaw are those constructed on the higher quality Cl. 4, 5, or 6 Sp. base or subbase materials (TS 27, 28, 29 and 31). The BDI and DF_1 values for these sections were typically within 10 days after the thaw completion date. On average, and with the exception of the SCI, all the maximum responses analyzed in this study appear to occur within 7 to 10 days either side of the thaw completion date. The AREA values are consistently closer to the end-of-thaw date than other parameters. Therefore, the AREA parameter appears to be a better indicator of the end-of-thaw date.

The results of the backcalculation analysis were used to construct seasonal stiffness change curves. The change over time in base and subgrade moduli for TS 30 are shown for 1994 through 1997 (Figure 18) and specifically for 1994 (Figure 19). Similar curves were obtained for the other sections. For all sections with a clayey subgrade, the minimum base modulus occurs sometime during mid-thaw. It is shown in Figure 19 that the thaw duration and the recovery period for the pavement structure is approximately 8 weeks.

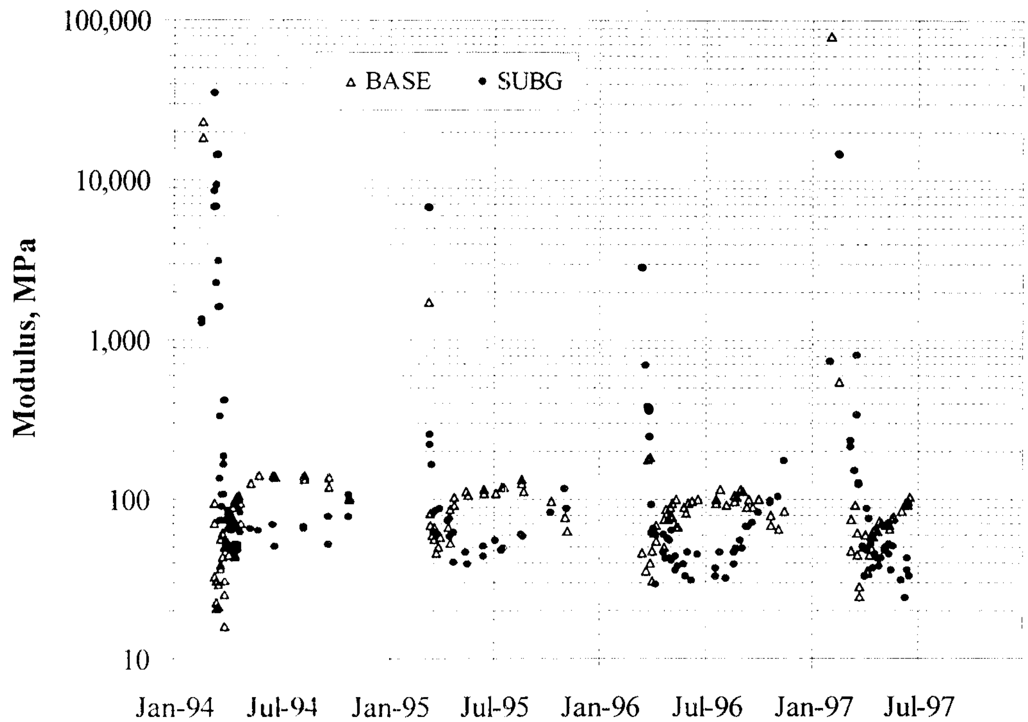


Figure 18. Seasonal variation in backcalculated moduli – Mn/ROAD test section 30.

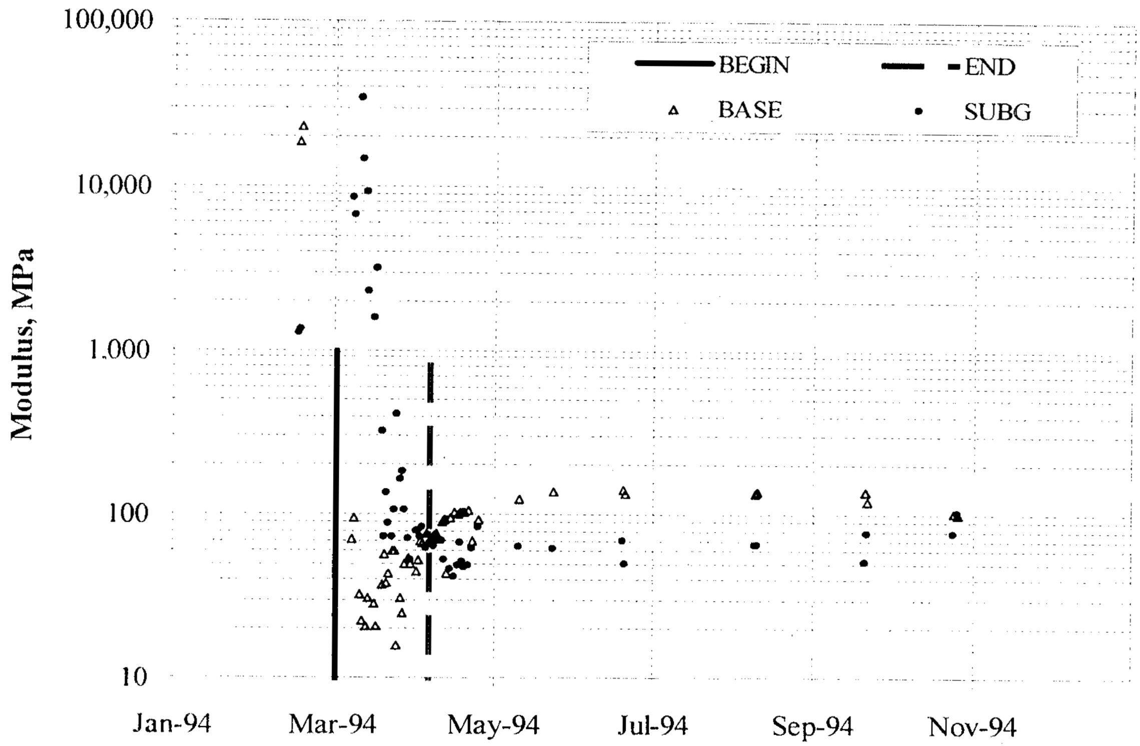


Figure 19. Variation in moduli with thaw begin and end for Mn/ROAD test section 30.

The rate of strength recovery with respect to base quality was investigated (Figure 20). Although the rate of recovery in the BDI was highest for TS 27, 28, and 31 (Cl. 6 and 5 Sp. base or subbase) no other trends were observed. This could possibly be due to site specific conditions, e.g., drainage and soil type.

In general, for 1995, 1996 and 1997, the increase in base layer modulus at the end-of-thaw relative to the minimum value at mid-thaw has been variable and ranged from 15 to over 100 percent. At two weeks past the end of thaw the recovered strength levels are at least 50 percent with some years seeing recoveries well over 200 percent. The two sections with aggregate bases having low fines (Cl. 5 and 6 Sp.) have overall higher moduli during the spring thaw relative to the base materials with high fines (Cl. 3 and 4 Sp.).

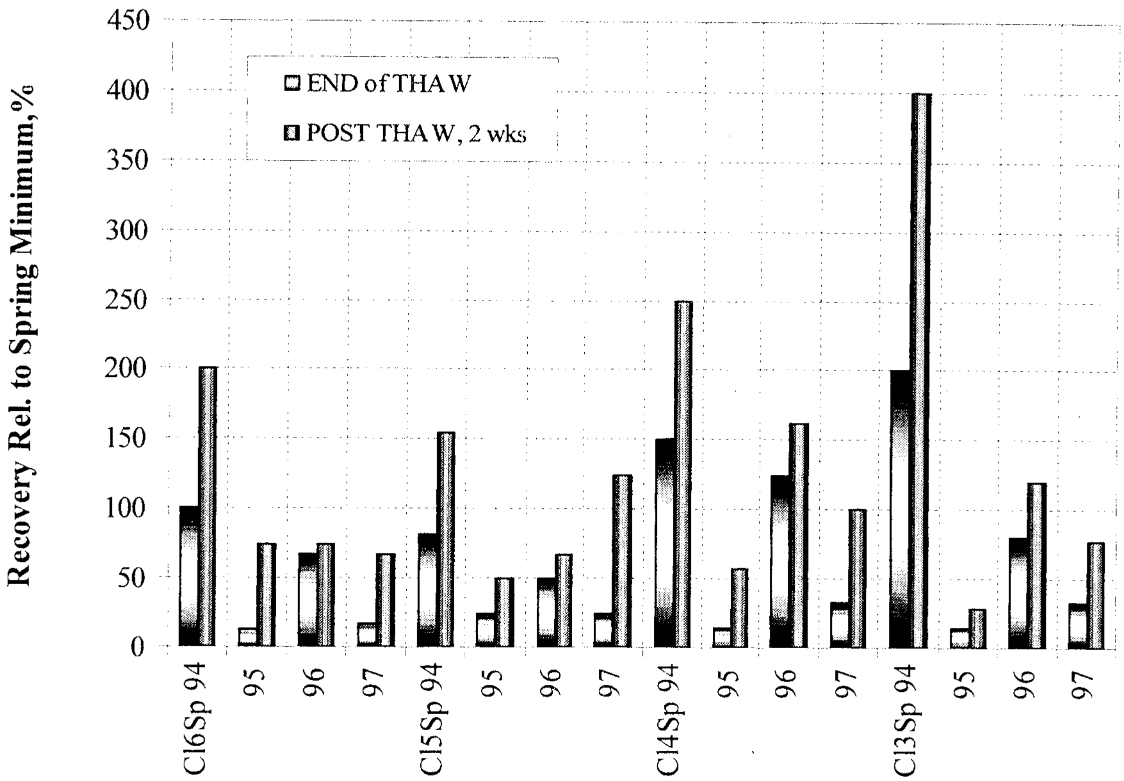


Figure 20. Comparison of recovery rates for different Mn/ROAD aggregate base materials, 1994 – 1997.

Summary

A new SLR procedure is suggested to improve the Minnesota's SLR procedure. The past procedure has placed the SLR 7 to 10 days too late, missing the critical initial thaw-weakened period. The additional damage due to premature pavement deterioration resulted in additional direct costs to the State of Minnesota and to local units of government. There were additional user costs associated with vehicle damage, increased travel time due to pavement condition, and lost time due to construction detours. Also, basing the end of SLR on deflection measurements has a distinct disadvantage due to the large number of roads that need to be tested weekly, also the logistics involved in setting up lane closures, travel time, equipment failures and other reasons. Another disadvantage of using deflection measurements was the large variability in deflections due to rainfall events and temperatures that were difficult to account for in weekly testing.

To improve Minnesota's SLR policy, the SLR procedure developed by WSDOT [11, 12] was applied and adjusted to Minnesota conditions. A revised reference temperature is used in the new SLR procedure to better predict the beginning of the thaw period for Minnesota. Historical daily temperatures showed the mean spring air temperature to vary from -0.9, -2.3, and -4.3°C (30.4, 27.9, and 24.3°F) for the months of January, February, and March, respectively. Therefore the air temperature required for thawing actually decreases from January to March due to the declination of the sun during the spring.

Using the FI and TI data along with the observed thaw duration, Equations 3 and 4 were evaluated for the prediction of the thaw duration in Minnesota. It was found that Equation 3 predicts a longer duration than the actual duration and that no correlation could be found between the FI, TI, and observed thaw duration using Equation 4. This means that, at least based on frost observations at Mn/ROAD, Equations 3 and 4 should not be used to estimate the date on which thawing is complete in Minnesota. A revised equation was developed to predict the thaw duration for Minnesota conditions that predicted the duration more accurately, however, the coefficient of determination was still fairly low ($R^2 = 0.5$).

The rate of strength recovery in the backcalculated moduli was investigated. In general, for 1995, 1996 and 1997, the increase in base layer modulus at the end-of-thaw relative to the minimum value at mid-thaw has been variable and ranged from 15 to over 100 percent. At two weeks past the end of thaw the recovered strength levels are at least 50 percent with some years seeing recoveries well over 200 percent. The two sections with aggregate bases having low fines

(Cl. 5 and 6 Sp.) have overall higher moduli during the spring thaw relative to the base materials with high fines (Cl. 3 and 4 Sp.). It was determined from historical observations ad measured data that it typically takes about 8 weeks for typical pavement structures to recover from the spring-thaw in Minnesota, and therefore the duration of SLR is fixed at 8 weeks in the new SLR policy.

The final procedure used is summarized in Mn/DOT Technical Memorandum No. 99-06-MRR-03 (Appendix A). In this new procedure, the beginning of the thaw period is predicted using the TI and the 3-day forecasted temperature for each SLR zone. The results shown in this chapter show that the air temperature required for thawing decreases from January to March in Minnesota due to the increase in the declination of the sun during the spring. Since the thaw can occur in late February or March, a variable reference temperature for calculating TI is used in Minnesota's new SLR policy.

CHAPTER FIVE

ESTIMATED SAVINGS

Introduction

Through research we are able to predict when spring thaw-weakening will occur using air temperatures measured and forecasted for most areas of Minnesota. It is estimated that a typical low volume asphalt road's life will be increased by about ten percent due to implementing improved SLR procedures.

The potential savings resulting from improved load restriction placement is expected to be substantial. In Minnesota there are about 39,000 miles of paved roads that do not meet the 10-ton spring load design standard and therefore should be restricted to lower loads during the spring. Included in these 39,000 miles are about 1,600 miles of state trunk highways, 23,600 miles of county state aid highways, 2,400 miles of municipal state aid city roads, and roughly 11,000 miles of other local roads constructed and maintained through local funding. The vast majority of these roads are paved with asphalt concrete, which has an annual construction and overlay cost of about $12,000 per mile per year. This cost is based on a present value construction cost of $210,000 per mile, which includes two overlays, a discount rate of 4.5 percent, and a total life of 35 years.

Unfortunately, the time before the first overlay, between overlays, and the total life are reduced if unanticipated damage occurs in the spring. The results in this chapter show that a delay in the start of SLR may result in more than one year of life lost before the first overlay and that complete reconstruction may be required after 32 years rather than the projected 35 years. Given these shortened periods, the actual annual cost would be about $12,500 per mile per year rather than $12,000 per mile per year. Multiplying $500 per mile per year by the number of miles of restricted roads that are most likely to sustain spring damage (about 75 percent of 39,000 or 29,000 miles) results in an annual cost of $14,000,000. Obviously this estimate is approximate and based on the costs and periods stated above and the conditions considered in the design example below.

Historical posting dates from 1986 through 1998 were compared to the posting dates predicted using the new technique. It was found that there is typically a week or more delay from the time that load restrictions should have been placed until restrictions were actually begun. This delay caused significant damage that can now be prevented. The damage results in additional direct costs to the State of Minnesota and to local units of government due to premature pavement deterioration. In addition, there are user costs associated with vehicle damage, increased travel time due to poor pavement condition, and lost time due to construction detours. These additional user costs are certainly important to the traveling public, however the accurate estimation of these costs is beyond the scope of this report.

The research results are also applicable to the rest of Minnesota's trunk highway system for at least two reasons. First, Mn/DOT currently allows a ten-percent legal load increase during the winter when the ground is frozen. This ten-percent load increase should be removed before any anticipated weakening. Second, Mn/DOT is asked to grant special permits for some unique loads. The correct application of these two policies requires knowledge of the strength of the roadway during the winter and spring so that excessive damage is prevented.

Design Example

Assume that a road is expected to carry about 50 trucks per day during the spring and that each truck will be restricted to 7-tons per axle. For that loading condition, a "typical" restricted road constructed on a clayey or silty soil subgrade found beneath about 75 percent of Minnesota's roads would have an asphalt pavement thickness of about three inches and an aggregate base thickness of about twelve inches. This design assumes that load restrictions will be in place in the spring when they are needed and that the 7-ton per axle loading will not be exceeded when the base and subgrade are weak. If load restrictions are not in place and the legal 10-ton per axle load is applied, then increased damage will result.

This damage can be quantified by comparing the fatigue and rutting damage predicted by the mechanistic-empirical pavement design software developed for Mn/DOT by the University of Minnesota [33]. Relative damage factors were computed for 10-ton-per-axle trucks and 7-ton-per-axle trucks on the "typical" restricted road during spring weakened conditions. It was found that the fatigue damage factor increased from 1 to about 2.5 and the rutting damage factor increased from 1 to about 4. To simplify the following calculations the greatest of these damage factors was used. This means that unrestricted loads during spring weakened condition result in about 4 times the expected damage.

However, the damage done per week during spring conditions is about five times greater than the damage done during an "average" week of the year. In fact, for the same loads and traffic volumes, about 10 percent of the total annual damage occurs each week during the spring (Figure 21). In order to prevent 10 percent of the annual damage from occurring every week during the spring, SLR are used to reduce the damage due to loads by the factor of 4 described above. Therefore, 10 percent can be reduced to 2.5 percent damage every week during the spring, thus saving about 1 percent of the annual damage per day. Therefore if SLR are delayed for 10 days, a 10 percent increase in damage results, and 10 percent less of the design life could be expected.

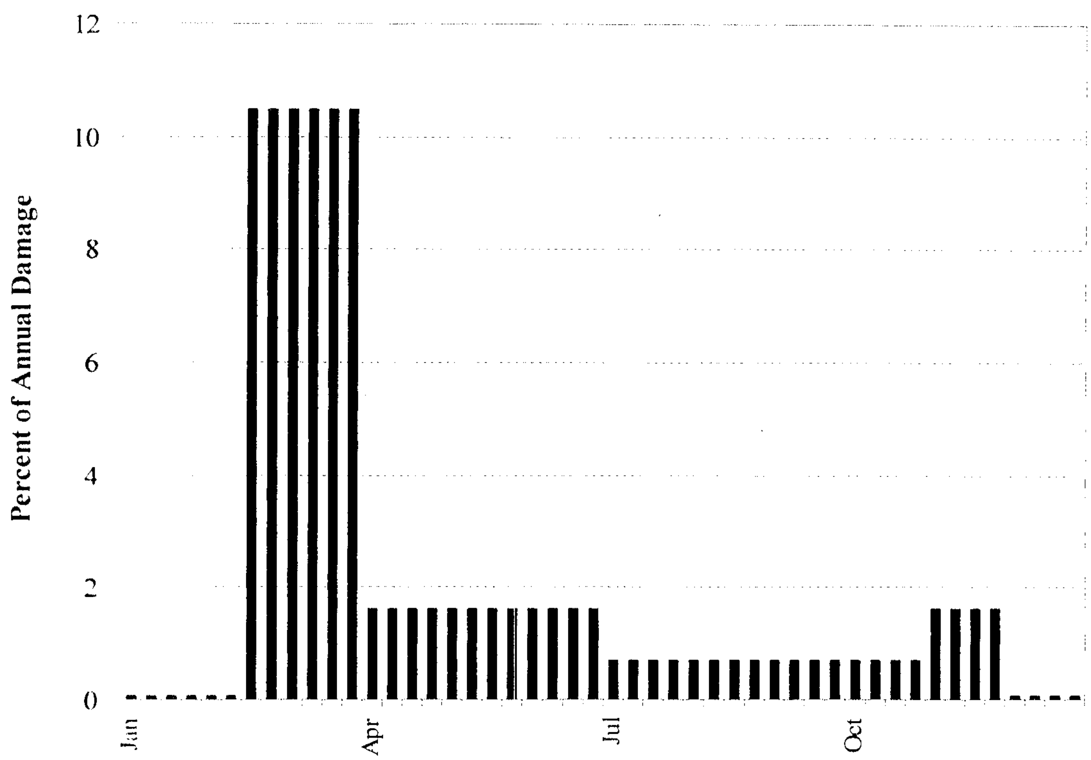


Figure 21. Relative damage calculated from the 1993 AASHTO Design Guide.

If a road is expected to last 15 years before the first overlay and if load restrictions were placed 10 days late in each of those years, then about 10 percent or 1.5 years would be lost. The result is that the road would need to be overlayed in 13 or 14 years rather than the expected 15 years. Similarly, the second overlay would to needed in about the 24th year rather than the 27th year and the pavement completely reconstructed in 32 years rather than 35 years.

Several conclusions can be made from the results of the mechanistic-empirical analysis performed using the Mn/PAVE (ROADENT) 1.8 software [33]. The combined effect of increased load and decreased roadbed stiffness means that extending the period of load restrictions for an additional week at the end of the restriction period would not even begin to compensate for a one-week delay at the start. In fact it may take as many as 28 weeks of reduced loads at the end of the restricted period to compensate for a one-week overload at the beginning. This is because trucks may be loaded to 10-ton per axle prior to placing SLR when the pavement structure is at its weakest. Two things were determined; four times as much damage is done by a 10-ton axle as a 7-ton axle and the same load creates about seven times as much damage at the beginning of the spring thaw compared to conditions in late spring. Therefore the damage done by a 10-ton-axle in the early spring is 4 * 7 or 28 times the damage of a 7-ton-axle in the late spring. In order to compensate for each day of overload at the start, 28 days of additional restrictions would be required in the late spring.

These results from the mechanistic-empirical analysis were compared to the damage factors suggested by the AASHO Road Test and the 1993 American Association of State Highway and Transportation Officials (AASHTO) Guide for the Design of Pavement Structures [34]. The "fourth power law," which was developed at the American Association of State Highway Officials (AASHO) Road Test, estimates that the increased load of 1.4 times (increase of axle weight from 7 to 10 tons) would result in about 4 times the damage. The equation found on page II-14 of the 1993 AASHTO Guide, estimates that the damage due to a 50 percent reduction in the roadbed modulus would be about five. Therefore the combined affect of increased load and decreased modulus would be 4 * 5 or 20 times.

Summary

It is well known that much more of a road's life is consumed during the spring than during other times of the year. To help define the relationship between applied load, in situ material conditions, and the resulting damage, mechanistic-empirical analyses were performed using Roadent 1.8. The first set of analyses investigated the affect of changing the load while maintaining the same material properties. Those analyses showed that failure to reduce loads resulted in about four times the expected spring damage. A second set of analyses was then completed in order to investigate the effect of changing the material properties while maintaining the same loads. For the second set of analyses the subgrade modulus was reduced by 50 percent and the aggregate base modulus was reduced by 75 percent. These analyses showed that even if the same loads were applied, that seven times as much damage occurred when the moduli were reduced to simulate spring conditions. Therefore, in order to compensate for each day of overload at the start, 28 days of additional restrictions would be required in late spring. These results compare favorably to the damage factors suggested by the AASHO Road Test and the 1993 AASHTO Guide for the Design of Pavement Structures [34].

There is no doubt that SLR are critical to achieving the expected design life of our roadways. A reasonable estimate of the damage caused by delaying the start of SLR is 1 percent of the annual damage per day of delay. Therefore, 10 days of delay each spring results in a 10 percent loss in the life of the roadway. This is an estimate for a well-maintained roadway in good condition. Roadways not meeting this criterion could be destroyed much faster.

To adequately quantify the financial and economic impacts of SLR, a comprehensive benefit/cost study should be completed. This was one of the primary recommendations of the Minnesota Legislature's SLR Task Force [3].

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Summary

Spring is a critical period for Minnesota's roads because the soil and aggregate base materials are in a weakened state during and after the frost leaves the ground. In order to prevent excessive roadway damage and protect Minnesota's investment it is important to place load restrictions when they are most needed, at the beginning of the spring thaw. This study was conducted to improve the Minnesota Department of Transportation's spring load restriction policy. The past policy was based on observations, measurements, and engineering judgement.

Spring weakening can be seen clearly in the falling weight deflectometer and the in situ instrumentation readings at Mn/ROAD. Unfortunately, if the weakening can be measured, then damage has already occurred and therefore it is important to be able to predict when this weakening will occur. Through research we are able to predict when this weakening will occur using air temperatures measured and forecasted for most areas of Minnesota. It is estimated that a typical low volume asphalt road's life will be increased by about 10 percent due to implementation of the SLR procedures described in this report. The potential savings resulting from improved load restriction placement are expected to be substantial since in Minnesota there are about 39,000 miles of paved roads that do not meet the 10-ton spring load design standard.

The Washington State Department of Transportation developed a thawing index equation based on air temperatures. This equation was evaluated and it was determined that it predicts thaw too late in Minnesota. The revised Mn/DOT equation works well during both February and March because it uses a variable reference temperature that decreases 0.56°C (1°F) per week during February and March. This relationship is the result of increased solar radiation as the sun rises higher in the sky during the spring.

Historical posting dates from 1986 through 1998 were compared to the posting dates predicted using the new technique. It was found that there was typically a week or more delay from the time that load restrictions should be placed until restrictions were actually posted. This delay caused damage that can now be prevented. The damage results in additional direct costs to the State of Minnesota and to local units of government due to premature maintenance and reconstruction. In addition, there are user costs associated with vehicle damage, increased travel time due to pavement condition, and lost time due to construction detours.

The result of this study was the adoption of a new procedure for placing SLR by Mn/DOT. The policy uses actual and forecasted average daily temperatures to determine when SLR should be placed. The duration of the SLR is fixed at 8 weeks. This allows the roadbed to recover most of its strength and it allows the transporters the ability to plan for the end of SLR. A new law effective 1999 also specifies that county, township and municipal roads will begin and end SLR in common with the state trunk highway system, unless the roads are posted otherwise.

The research results are also applicable to the rest of Minnesota's trunk highway system for at least two reasons. First, Mn/DOT currently allows a ten-percent load increase during the winter when the ground is frozen. This ten-percent load increase should be removed before any anticipated weakening. Second, Mn/DOT is asked to grant special overload permits for some unique loads. The correct application of these two policies requires knowledge of the strength of the roadway during the winter and spring so that excessive damage is prevented.

Conclusions

Based on the results presented it is reasonable to conclude the following:

- Due to the rapid decrease in strength at the beginning of the thaw, each day of delay in implementing restrictions is equivalent to 28 additional days of reduced loads at the end of the restricted period.
- When the 10 percent increase in winter weight limits is not removed prior to the spring-thaw period. the delay in placing SLR is that much more severe.
- It is possible to predict when spring thaw weakening will occur using air temperatures to calculate the thawing index (TI). Air temperatures are measured and forecasted for most areas of Minnesota.
- The reference temperature used to calculate the TI changes 0.5°C (1°F) per week during February and March due to the increase in the sun's declination.
- The predicted thaw durations from Equation 3, 4 and 7 were found to be too variable for use.
- Based on deflection and frost depth measurements the maximum deflection parameters correlate well to frost depths.
- The date of minimum strength with respect to the end of thaw was investigated and found to be variable. Overall, the deflection parameters investigated show an increase in stiffness within three weeks following the thaw completion date. However, peak BDI and DF_1 values for the sections constructed on Cl. 5 or 6 Sp. bases occur within 10 days of the thaw completion date.
- The base layer modulus increase at the end-of-thaw relative to the minimum at mid-thaw has ranged from 15 to over 100 percent. At two weeks past the end of thaw, the recovered strength levels are at least 50 percent.

- The two sections with aggregate bases having low fines (Cl. 5 and 6 Sp.) have overall higher moduli during the spring thaw relative to the higher fine content base materials (Cl. 3 and 4 Sp.).
- The two granular subgrade sections do not exhibit a noticeable peak deflection value and the subgrade modulus is relatively constant. The AREA parameter, however, does show a noticeable peak, with the maximum value being attained near the end date of the thaw period.
- The exact financial and economical impacts of SLR on Minnesota's taxpayers and highways system are not known at this time.

Recommendations

The following recommendations are made in regard to estimating placement and removal dates for spring load restrictions:

- Shorten the response time for placing restrictions to 3 days or less. Use the Internet and phone to provide official notice of SLR rather than mass mailings. Use the Internet to display a map of Minnesota with colors indicating the status within each zone.
- Use the revised air temperature thawing index (TI) to begin SLR. The criterion used to determine when load restrictions should be placed is a TI greater than 15°C-days (25°F-days) with predicted increases based on a three day forecast of the daily air temperatures.
- Use the 3-day forecasted temperatures to calculate the TI for each zone in Minnesota to better predict the beginning of the critical thaw period.
- Use the following locations are used to monitor the average daily air temperature: Bemidji, Brainerd, Duluth, International Falls, St. Cloud, Twin Cities, Redwood Falls, Mankato, Worthington and Rochester.
- Based on testing performed on pavement sections across the state, eight weeks is required for the pavement base and subgrade layers to regain sufficient strength to support heavy truck loads, thus the SLR period should be fixed at 8 weeks. Additional research would be required to modify this duration period.
- Given conditions are far worse at the beginning of the spring thaw than the end, and because the duration of SLR has been fixed at 8 weeks it is far more effective to place restrictions early than to delay their removal.
- Based on historical data, it seems reasonable that restrictions should always be planned to be in place no later than March 8 in the southern area of the state and by March 15 in the central

and northern areas of the state. Earlier dates are likely, but later dates should not be considered.

- The 10 percent increase in winter load limits must be removed prior to placing SLR.
- Because of the difficulty in estimating precisely when conditions will deteriorate and because of the variation of conditions across the states, it is recommended that further research be done to determine a more mechanistic approach for placing and removing the increased winter load limit period.
- A comprehensive benefit/cost study should be completed to adequately quantify the financial and economic impacts of SLR on Minnesota's taxpayers and highway system.
- A study should be completed to determine if the boundaries of the zones in Minnesota are adequate for correct placement of SLR.

REFERENCES

1. Van Deusen, D, C. Schrader, D. Bullock and B. Worel, "Recent Research on Springtime Thaw Weakening and Load Restrictions in the State of Minnesota," *Transportation Research Record*, National Research Council, Washington, D.C., 1998.

2. --- "Transportation" Minnesota Statutes, Volume 5, Chapters 160 - 169, Official Publication of the State of Minnesota, 1998.

3. Mn/DOT Seasonal Posting Task Force. "Recommended Guidelines for Imposing and Lifting Springtime Restrictions." Mn/DOT Report, St. Paul, MN, 1986.

4. Newcomb, D.E., Chadbourn, B.A., Van Deusen, D.A., and Burnham, T.R. "Initial Characterization of Subgrade Soils and Granular Base Materials at the Minnesota Road Research Project." *Report No. MN/RC-96/19*, Minnesota Department of Transportation, St. Paul, MN, 1995.

5. --- "Spring Load Restrictions Task Force, Final Report" Mn/DOT Report, St. Paul, MN, 2000.

6. Rutherford, M.S. "Pavement Response and Load Restrictions on Spring Thaw-Weakened Flexible Pavements." *Transportation Research Record 1252*, Transportation Research Board, National Research Council, Washington, D.C., 1989.

7. Scrivner, F.H, Peohl, R., Moore, W.M., and Phillips, M.B. "Detecting Seasonal Changes in Load-carrying Capacity of Flexible Pavements." *NCHRP Report No. 76*, Highway Research Board, Washington, D.C., 1969.

8. Van Deusen, D., Schrader, C., and Johnson, G. "Evaluation of Spring Thaw Load Restriction and Deflection Interpretation Techniques." *Proc., Eighth International Conference on Asphalt Pavements*. Seattle, WA, 1997.

9. Nordal, R.S. "Detection and Prediction of Seasonal Changes of the Bearing Capacity at the Vormsun Test Road." *Proc., International Symposium on the Bearing Capacity of Roads and Airfields*, Trondheim, Norway, 1982.

10. Nordal, R.S., and Saetersdal, R. "Norwegian Practices for Axle Load Restrictions in Spring Thaw." *Proc., International Symposium on the Bearing Capacity of Roads and Airfields*, Trondheim, Norway, 1982.

11. Washington State Department of Transportation, *WSDOT Pavement Guide, Vol. 2,* Seattle, WA, 1995.

12. Rutherford, M.S., J.P. Mahoney, R.G. Hicks, and T. Rwebingira. *Guidelines for Spring Highway Use Restrictions*. Report No. FHWA-RD-86-501. Washington State Department of Transportation, 1985.

13. Mahoney, J.P. "The Evaluation of Frost Related Effects On Pavements." *Summary Report WA-RD 67.2*, Washington State Department of Transportation, Seattle, WA, 1985.

14. Mahoney, J.P., Rutherford, M.S., and Hicks, R.G., "Guidelines for Spring Highway Use Restrictions." Report FHWA-TS-87-209, 1987.

15. Washington State Department of Transportation, *WSDOT Pavement Guide, Vol. 3*, Seattle, WA, 1995.

16. Rwebingira, T., Rutherford, M.S., Mahoney, J.P., and Hicks, R.G., "Development of Spring Load Restrictions for Local Roads." Transportation Research Record 1128, 1987.

17. --- "Truck Weight Limits: Issues and Options," Committee for the Truck Weight Study, Special Report 225, Transportation Research Board, National Research Council, Washington, D.C., 1990.

18. Refsdal, G., "The Lifting of Axle Load Restrictions During Spring Thaw - A Norway Experiment" *Proceedings from the Fifth International Conference on the Bearing Capacity of Roads and Airfields*, Editors: R.S. Nordal, Norwegian University of Science and Technology, and G. Refsdal, Norwegian Public Roads Administration, Vol. 1, Trondheim, Norway, July 1998.

19. Janoo, V.C, and R.L. Berg. *Predicting the Behavior of Asphalt Concrete Pavements in Seasonal Frost Areas Using Nondestructive Techniques*. Report No. 90-10. USAE Cold Regions Research and Engineering Facility, 1990.

20. Janoo, V.C., and R.L. Berg. Predicting Pavement Response During Thaw Weakening Periods Using the Falling Weight Deflectometer. Proceedings, *Third International Conference on the Bearing Capacity of Roads and Airfields*. Trondheim, Norway, June 1990.

21. Janoo, V.C., and R.L. Berg. *Performance of Asphalt Concrete Airport Pavements During Thaw Weakening Periods*. Report No. 91-7. USAE Cold Regions Research and Engineering Laboratory, 1991.

22. McBane, J.A., and G. Hanek. Determination of the Critical Thaw-Weakened Period in Asphalt Pavement Structures. In *Transportation Research Record 1089*, TRB, National Research Council, 1985.

23. Yesiller, N., Benson, C.H., and Bosscher, P.J. "Comparison of Load Restriction Timings Determined Using FHWA Guidelines and Frost Tubes." *Journal of Cold Regions Engineering*, ASCE, Vol. 10, No. 1, 1996.

24. Wilson, T. *Spring Restrictions: Limits and Timing,* Report No. SD93-03-F. South Dakota Department of Transportation, 1994.

25. --- "User Guide to the Frost Resistivity Probe," Minnesota Department of Transportation, Office of Materials and Road Research Pamphlet.

26. Atkins, R.T. "Determination of Frost Penetration by Soil Resistivity Measurements." *Special Report No. 79-22*, USAE Cold Regions Research and Engineering Laboratory, West Lebanon, NH, 1979.

27. Schrader, C., and Johnson, G. "Subsurface Instruments Installation Procedures." *Proc., The 4th International Conference on the Bearing Capacity of Roads and Airfields*, Vol. 2, Minneapolis, MN, 1994.

28. Van Deusen, D. "Selection of Flexible Pavement Backcalculation Software for the Minnesota Road Research Project." *Report MN/PR-96/29*, Minnesota Department of Transportation, St. Paul, MN, 1996.

29. Newcomb, D.E., Van Deusen, D.A., Jiang, Y., and Mahoney, J.P. "Considerations of Saturated Soil Conditions in Backcalculation of Pavement Layer Moduli." *Transportation Research Record 1473*, Transportation Research Board, National Research Council, Washington, D.C., 1995.

30. Lukanen, E.O., Stubstad, R.N., and Briggs, R., "Temperature Prediction and Adjustment Factors for Asphalt Pavements." FWD User's Group Meeting, 1996.

31. Kim, R.Y., Hibbs, B.O., and Lee, Y.C., "New Temperature Correction Procedure for FWD Deflections of Flexible Pavements." Proceedings, The 4th International Conference on the Bearing Capacity of Roads and Airfields, 1994.

32. Chisholm, R.A., and W.A. Phang. Measurement and Prediction of Frost-Penetration in Highways. In *Transportation Research Record 918*, TRB, National Research Council, 1977.

33. Timm, D.H., B. Birgisson and D.E. Newcomb, "Mechanistic - Empirical Flexible Pavement Thickness Design, The Minnesota Method," Mn/DOT Staff Paper, 1996- 1999.

34. American Association of State Highway and Transportation Officials, "Guide for Design of Pavement Structures," 1993.

APPENDIX A - MN/DOT TECHNICAL MEMORANDUM

GUIDELINES FOR POSTING SPRING LOAD RESTRICTIONS

MINNESOTA DEPARTMENT OF TRANSPORTATION

Engineering Services Division

Technical Memorandum No. 99-06-MRR-03

February 1, 1999

TO: Distribution 57, 618 and 650

FROM:

David S. Ekern,

Director/Assistant Chief Engineer

Engineering Services Division

Patrick Hughes,

Director

Operations Division

SUBJECT:

Guidelines for Posting Spring Load Restrictions

This Technical Memorandum will continue in force until June, 2002, unless superceded or placed in the Geotechnical and Pavement Manual prior to that date.

PURPOSE AND USE

The purpose of this technical memorandum is to provide a uniform statewide procedure for determining the dates that spring load restrictions will be placed and removed on the Minnesota Trunk Highway System.

POLICY

1. The Districts will submit their restricted roadway segments for the annual *ROAD RESTRICTION MAP* to the Director of the Office of Road & Vehicle Information and Services by December 31 of the preceding year.
2. The annual *ROAD RESTRICTION MAP* will be mailed to all those on the Mn/DOT mailing list in late January or early February, along with an explanation

of the new procedure for notification of postings. This mailing will be the only mail notification of the procedure to the general public.

3. A toll-free telephone number (1-800-723-6543) and local telephone number (651-406-4701) and Internet Site (http://mnroad.dot.state.mn.us) have been established in order to provide information on postings in each frost zone as quickly and conveniently as possible. A 3-day notice of restrictions will be provided using a recorded telephone message with more detailed status reports available on the Internet site. Mailings will no longer be used.
4. The start of the load restriction period will be determined for each zone using measured and forecast daily temperatures for several cities within each frost zone. The criteria used to determine when the load restrictions will be placed is when the cumulative thawing index for a zone exceeds 25 F degree-days based on the 3-day weather forecast, with predicted increases well in excess of 25 F degree-days. The intent is to use the 3-day advance forecast temperatures to ensure that the postings are on at the beginning of the thaw and at the same time provide 3 days of notice to the public that the posting period is coming.
   The calculation is made using the following formula:

   Thawing Index = Average Daily Temperature - Reference Temperature

   The reference temperature varies linearly from 29 degrees F on February 1 to 24 degrees F on March 15.

   The cumulative thawing index is the summation of the daily thawing indices.
5. The load restriction period will be 8 weeks in duration for all frost zones.

Implementation

The procedures goes into effect spring of 1999. Any questions regarding this Technical Memorandum should be directed to John Siekmeier the Physical Research Section, Office of Materials and Road Research at 651/779-5299.

Any questions regarding the publication or distribution of this technical memorandum should be referred to Andrew Halverson, Acting Design Standards Engineer, at 651/296-3023 or Helen Blair, Administrative Assistant, at 651/296-2381.

MEMO

Engineering Services Bureau

Mailstop 120

395 John Ireland Boulevard

St. Paul, MN 55155

DATE: February 1, 1999

TO: Distribution 57, 618, and 650

FROM: Dave Ekern

Director/Assistant Chief Engineer

Engineering Services Division

PHONE: (651) 296-6884

SUBJECT: Technical Memorandum 99-06-MRR-03

Technical Memorandum 99-06-MRR-03 explains the new Mn/DOT policy for posting spring load restrictions. During the initial implementation of this policy personnel from the Physical Research Section, Office of Materials and Road Research will contact the Area Maintenance Engineers, District State Aid Engineers, District Materials Engineers, Central Office State Aid Division and Road and Vehicle Information and Services Section when the restrictions should be placed in a specific frost zone. The Area Maintenance Engineers will notify the County Engineers in their respective sub-areas. This notification will be only for spring, 1999. After 1999 the policy will be considered implemented and the Internet site and telephone messages will be the only notification provided to Mn/DOT personnel on a regular basis.

Office of Research Services
395 John Ireland Blvd., Mail Stop 330
Saint Paul, Minnesota 55155

(651) 282-2274