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Investigation of Winter Pavement Tenting

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This research looked at the perceived causes and winter maintenance strategies of tenting through a survey sent to municipal, county, and state engineers in Minnesota, before conducting field research based on the theory that deicing chemicals, sands, and crack sealing all influence pavement tenting. The research found that crack sealing can reduce the roughness and height of tented cracks.

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Investigation of Winter Pavement Tenting

Final Report

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Executive Summary

This research looked at the perceived causes and winter maintenance strategies of winter pavement tenting through a survey sent to municipal, county, and state engineers in Minnesota. Field research was performed based on the theory that deicing chemicals, sands, and crack sealing all influence pavement tenting.

Data from test section monitoring, profile measurement, and test pit excavations was collected for several winters during periods when roads were deemed likely to produce tenting. A set of measurements was obtained for examining relationships between tenting severity, temperature conditions, the presence of deicing chemicals, and the effect of maintenance activities.

Measurement of base materials showed that the concentration of deicing salts decreased with depth and distance from pavement cracks. Measurements also showed that crack sealing can reduce roughness and height of tented cracks.

Introduction

The term "pavement tenting" refers to a condition of localized heave that develops at pavement cracks or joints during winter weather. Tenting is traditionally associated with transverse cracks in bituminous pavement. Severe winter pavement tenting will impact the ride quality. In other studies the mechanism of tenting has been investigated, with results supporting the hypothesis that the presence of road deicing chemicals can contribute to tenting.

In this report a literature review is presented to give the reader background on the current theories that account for tenting of pavement cracks during winter. A survey was sent to Minnesota municipal, county, and state engineers to determine how tenting is perceived. Survey responses cited surface type, treatments, and base material as being the most important factors contributing to tenting.

The field investigation was based on the theory that deicing chemicals, sands, and crack sealing all influence pavement tenting. Field methods were chosen mainly to gain information on winter conditions, when the test sites would likely show tenting.

Periodic cold weather site surveys were performed. The work included measurement, sampling, and documenting conditions. Two forensic projects were also included, each comprised of cutting excavation pits and sampling the surface and base materials. Materials from the excavation pits were also sampled. Additionally, longitudinal profile measurements of a number of sites were performed.

Test section monitoring was performed for several winters in order to observe the impact of various treatments on tenting severity.

Chapter 1: Literature Review

A literature review was performed in order to gain background information on the current theories accounting for winter tenting of pavement cracks and potential methods of tracking and analyzing tenting.

The Minnesota Department of Transportation (Mn/DOT) Pavement Management Unit [1] analyzed the ride quality conditions for crack sealed and unsealed tented cracks. Tented cracks are the cause or extremely rough riding during the spring and winter. Several Minnesota highways located in Mn/DOT District-1 were tested to compare ride severity between winter and summer conditions, and to compare tenting on sealed and unsealed cracks.

Testing was done in September 2003 and February 2004 with a Mn/DOT Pathways Van Class I laser profiler, measuring the longitudinal profile and collecting video images of the pavement surface. The longitudinal profile from each roadway was run through software that simulated a 10-ft rolling straightedge.

The analysis showed that for these subject roads, the cracks were spaced at about 30 foot intervals with tented crack heights between 0.15 and 0.2 inches. Plots and video information were used to determine the height of the tented cracks. The analysis phase established the minimum height criterion of 0.10-in. for a crack to qualify as "tented".

All of the sections exhibited some tented cracks and were rougher in February than they were in September. A decrease in ride quality ranging from 17 to 25 percent was attributed to the tented cracks. Overall, 44 percent of the sealed cracks were tented compared to 56 percent of the unsealed cracks. The average height of the tented cracks that were sealed was 0.16 inches compared to 0.18 inches for the tented cracks that were unsealed. This data suggests that sealing cracks reduces the amount of cracks that tent and also the height of the tenting. Mn/DOT also found that some of the sealed cracks also showed "cupping" that was equal to the tented crack height and covered the same length of pavement on each side of the cracks.

Fradette [2] measured winter roughness on five road sections using the International Roughness Index (IRI). Wavelengths from longitudinal profile data were used to study the influence of both subgrade differential heave and tenting. Subgrade differential heave is detected by isolating the long wavelengths (> 3 m) and tenting is detected by isolating the short wavelengths (< 3 m) of the longitudinal profile. Driver safety is most affected by short and medium wavelengths.

In this study, profile data was separated into sinusoidal signals that were then recombined according to wavelength. At the 3 m wavelength smoothing and antismoothing was done to highlight the short and long wavelengths, followed by recalculating IRI. Resurfacing techniques correspond to short wavelengths and reconstruction for long wavelengths. Researchers found long wavelength deformations were between 5 to 12 m long for these soils.

The researchers noted that IRI drops rapidly when cracks return to their original positions after a partial thaw of the top part of the pavement and prior to the subgrade thaw. Additional analysis showed that surface phenomena have a dominant effect on the winter roughness evolution. Also, a slow progression of the freezing front, possibly by a period of warming, immediately decreased IRI during that period.

Fradette showed that winter roughness is greatly influenced by both differential frost heaving in subgrade soils and by tenting of transverse cracks. It was also shown that differential frost heaving coincided with the freezing front reaching a heterogeneous, frost susceptible, subgrade soil.

In 2004 Gonzalez [3] conducted a national review of the applications of Recycled Concrete Aggregate (RCA) for the Federal Highway Administration. The review consisted of a survey of State Transportation Agencies to determine the current uses of RCA. This document was included in the literature review because anecdotal evidence is often given to associate tenting with RCA base materials.

Findings showed that many states are using RCA in pavement base layers. Many of the states, including Minnesota, are publishing permissive specifications for blends of RCA asphalt material. Minnesota allows 3% asphalt cement by dry weight of the aggregate. This amounts to including about 50% recycled asphalt pavement. Gonzalez notes that excessive working of the RCA base will segregate the base materials and that compacting RCA bases in a saturated state aids in the migration of fines throughout the mix. The tendency for RCA bases to re-cement can cause an over-stiff condition that leads to reflective cracking.

In 1997 Dore [4] studied the effect of salt concentration on frost heave on a standard crushed stone base material. Prior to the experiment, the material was verified as non-susceptible to frost according to standard methods. Specimens were prepared with salt concentration varying with height and placed in a moist condition with the water head below mid-height. The specimens were then subjected to a constant cooling rate.

Results showed that for these conditions the material performed in a frost susceptible manner. Additionally, it was shown that the movement of the freezing front can parallel heat flow because a fusion temperature gradient exists in the presence of salt.

In 1997 Mn/DOT [5] reported on the effectiveness of crack sealing in solving tenting in Flexible Asphalt Pavements". Six Minnesota districts compared sealed and non-sealed performance. It was found that at that time in Minnesota, sealed roads had approximately 38 percent less cracking than roads left unsealed.

Kestler [6] researched winter pavement tenting from 1993 – 96. Results from a field test program provided a discussion of causes and mechanisms of tenting though means of preventing tenting remain unidentified.

Kestler reports that transverse cracks were monitored for salt concentration, moisture content, subsurface temperature, freezing point depression, and heaving for several winter and spring seasons. The cause for tenting was determined to be the intrusion of winter maintenance salt and sand mixture into the base. Available water, cracked asphalt, winter maintenance salt-sand mix, freeze-thaw cycling of the base course, and the phase diagram of sodium chloride all appear to be necessary components for tenting. Tenting is frequently exhibited by pavements that are in otherwise good condition, and a year of severe tenting may be followed by a year of negligible tenting.

Tenting has also been observed more frequently in longitudinal slope sections where salty surface water can easily flow into transverse cracks.

During the fall of 1993 and winter of 1994 several test pits were excavated at cracks for in-situ testing and sampling. Density, moisture content, sieve and hydrometer analyses, and conductivity tests were performed. A ridgeline of fine material was exposed in the test pits. The ridge followed the crack path but the amount of material found there was too small to totally account for tenting. The ridgeline samples contained very high percentages of material finer than 0.02 mm (ref. Casagrande's frost susceptibility). Material in and near the crack had greater frost susceptibility than did the base course, possibly the result of fines being washed into the crack from maintenance sand and degradation of HMA at the crack. No density or salinity trends were detected.

In 1996, two sites were instrumented to monitor subsurface temperatures, moisture, salinity, freezing point depression, and elevation surveys were conducted. Excavation and testing results later showed that the water table and other lower level moisture sources were sealed off from the structure once frost reached an appreciable depth. The HMA crack was the only point of entry for water into the pavement system. Salt concentration was found to be significantly less at substantial vertical and horizontal distances from the HMA crack. However, salt concentration showed random fluctuations with increasing distance from the crack. The lack of pattern was attributed to the complex history of freezing and thawing of the contaminated base course at varying temperatures and varying vertical and horizontal distances from the HMA crack.

To eliminate tenting symptoms, Kestler recommends removing contaminated base material before resurfacing. Surface course overlays or similar measures are likely to undergo reflective cracking, thereby allowing continued salt intrusion. Crack sealing may temporarily stop salt intrusion.

Sharma's [7] 1991 report describes measurements performed for tented cracks. Findings showed that ride quality deteriorated as a result of crack tenting. However, neither the level of transverse crack deterioration nor the subgrade soil type affected tent magnitude. Tenting severity depended on the frequency of transverse tenting.

Additional work was done examining the feasibility of performing drain retrofits to tented cracks.

Chapter 2: Survey

A survey of Minnesota municipal, county, and state engineers was conducted to determine regional perceptions about winter pavement tenting. Twenty-four responses were received. The map of Minnesota shown in figure 1 highlights regions where, according to survey response, tenting deformations have or have not been found.

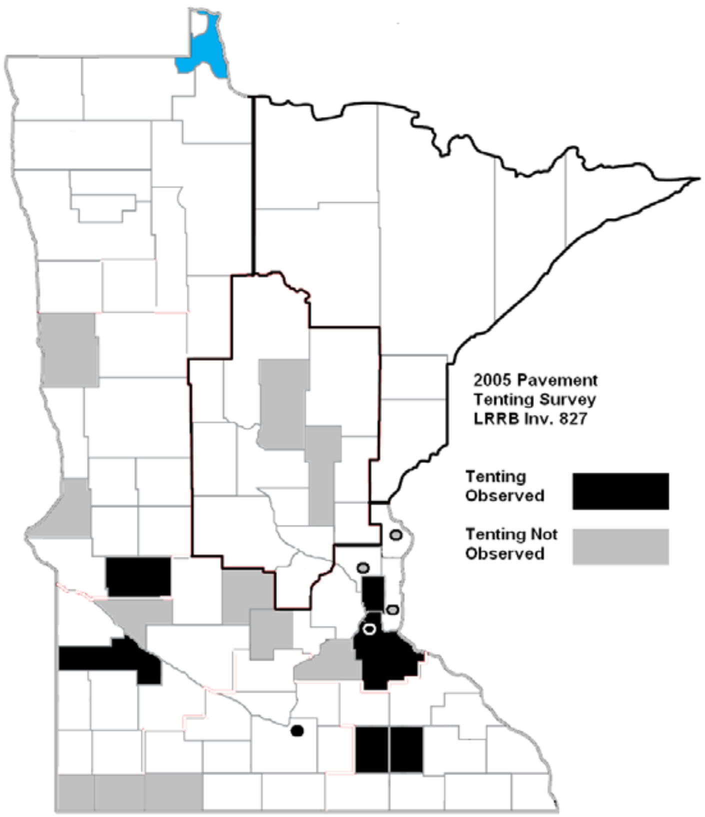

Figure 1 Tenting survey response, winter 2004 – 05.

From the survey it was found that 37.5% of respondents identified winter pavement tenting occurring in their local road network. When asked to identify distress level, respondents estimated of that 44% of tented pavements show low, 30% moderate, and 26% high severity. When estimating extent, 70% of the respondents replied that up to 25% of their network was tented (figure 2).

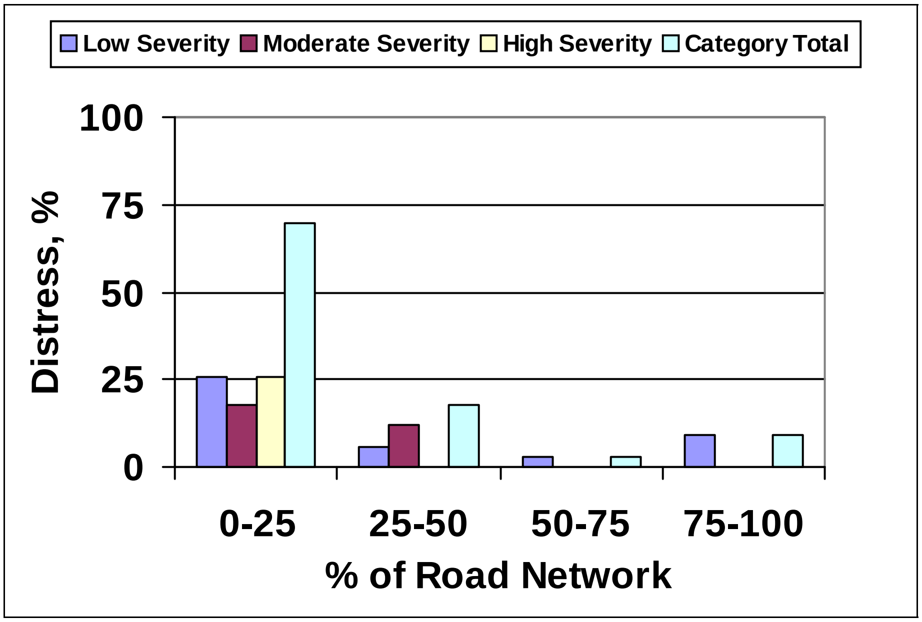

Figure 2 Results, pavement tenting survey, winter 2004 – 05.

The pavement structures that survey respondents considered either tent-resistant or tent-susceptible are listed in Table 1.

Table 1 Survey of Structural Layer Susceptibility to Tenting Deformation.

Tent Susceptibility	**Structure (# responses)**			
	Surface	***Base***	***Subbase***	***Subgrade***
☐ Yes	Bituminous (7) General material (2)	Gravel (1) Class 5 (1) Class 6 (1) Recycled bit (1) Recycled concrete (1) Bituminous (1) Concrete (1) General material (2)	Class 7 (1) Granular (1) Aggregate base (1) General material (3)	Heavy (1) Sand (3) General material (2)
☐ No	Concrete (1)	Granular (1)	Granular (1)	
☐ Both		General material (2)	General material (2)	General material (1)

Respondents were also given the opportunity to include general comments about pavement tenting. Some of the comments focused on the following points:

Survey Comments:

- deicing chemicals may contribute to tenting phenomenon but are not necessarily the major factor since deicing is used on all highways but they do not all react with the tenting phenomenon
- when water is able to move vertically and/or horizontally out of transverse cracks it can be trapped and frozen, creating an ice lens that pushes the pavement up

- crack filling does prevent tenting (2 responses)
- salted hills show most severe tenting with salted arterials next
- tenting seems to be associated with crack seal failures
- worst sections were bituminous over concrete (2 responses)
- base and subbase materials have low binder (P200) content and have not seen the tenting effect
- tenting occurred only once and coincided with above average rain in the late fall followed immediately by record cold temperatures - many roads remained tented all winter
- an aggressive route and seal and seal coat program reduces tenting
- tenting is either a minor problem or agency does not experience tenting (7 responses)

Figure 3 shows how survey respondents evaluated the effectiveness of various crack maintenance techniques. Figure 4 reports the usage frequency of deicing product type among respondents.

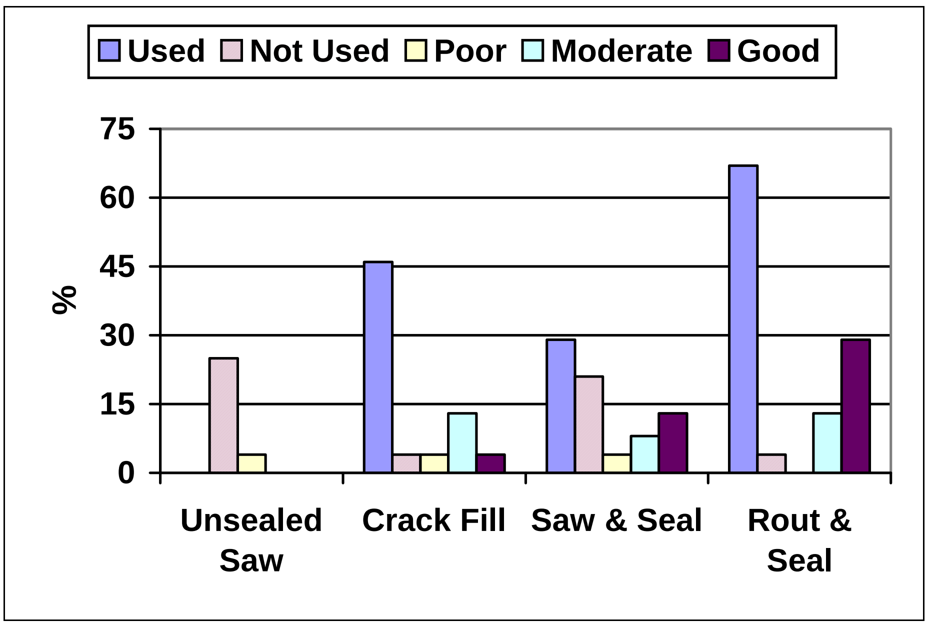

Figure 3 Crack maintenance effectiveness against pavement tenting.

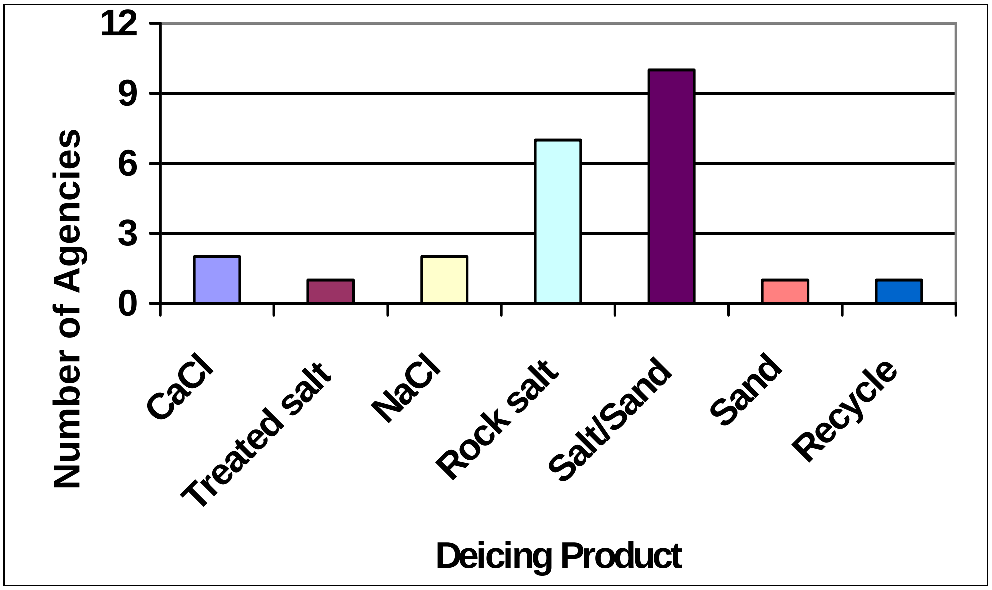

Figure 4 Deicing product used by survey participants.

Figures 5 and 6 shows deicing application information from Table 2, all converted to tons/lane mile.

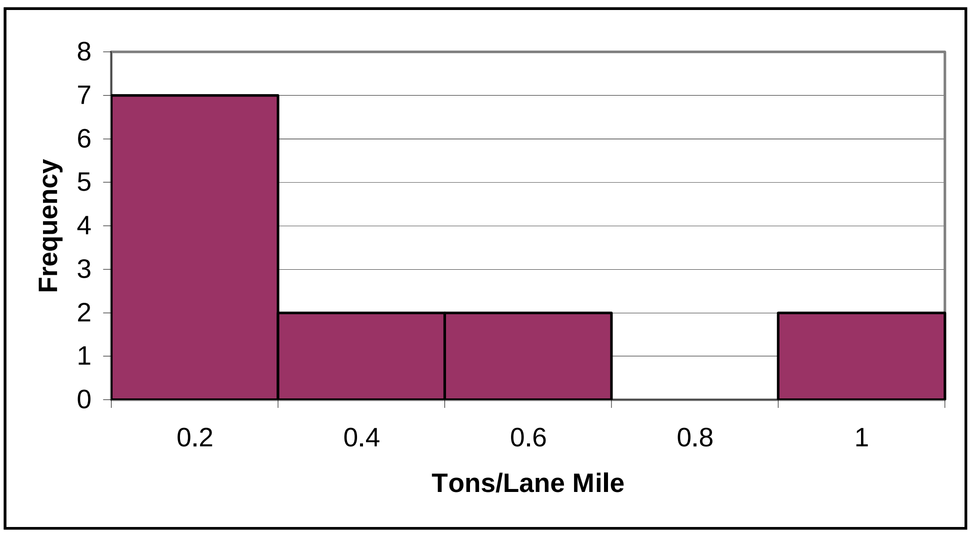

Figure 5 Deicing salt usage rate histogram.

Table 2 Deicing Protocol for Survey Respondents.

Rate	Method	Equipment
10 cy/8 miles.	Back spreader.	Trucks.
1200 lbs/mile.	Sander (non calibrated).	Tandem and single axel.
140 - 600 lbs/22-lane mile.	Premixed in stockpile with MgCl2.	Tailgate sanders.
200 - 400 tons/lane mile.	Tailgate spreader/spinner.	Trucks.
2000 lb/mile.		Auger w/ spinner sander.
250 lb/lane mile.	Standard spreader.	Standard sander spreader.
300 lb/lane mile.	Truck Sander/spreader.	Tandem/single axel trucks. Swenson spreader, Falls plows.
40 gallons/lane mile.	Streamed out LCS - 10% corn salt with 90% brine solution.	Low pressure electric pump with 6 inch spaced nozzles on pvc spray.
400 - 800 lbs/lane mile depending on event.	Computerized spreaders, calibrated annually.	Component Tech and Force America.
400 lb/mile.	Spinners.	Tandems w/pre wetting tanks.
500 lb/road mile.	Auger and spinner.	Snowplow truck, box, sander.
600 - 800 lbs/mile.	Sander.	Dumps.
600 - 800 lbs/mile.	Sander.	Dumps.
600 lbs/lane mile.	Truck with sander.	Truck with sander.
unknown		Truck with sander.
VARIABLE depending on conditions.	Spinner sander.	Monroe sander.
VARIABLE depending on conditions.	Spread on centerline with equipment retro fit on plow trucks.	Class 33 and Class 35 plow trucks.
VARIABLE Depending on Conditions.	Tailgate sanders.	Trucks.
Where needed.	Sander (broadcast)	Trucks.
	We sand hazard areas only. Stop signs intersections, etc.	Truck with sander.

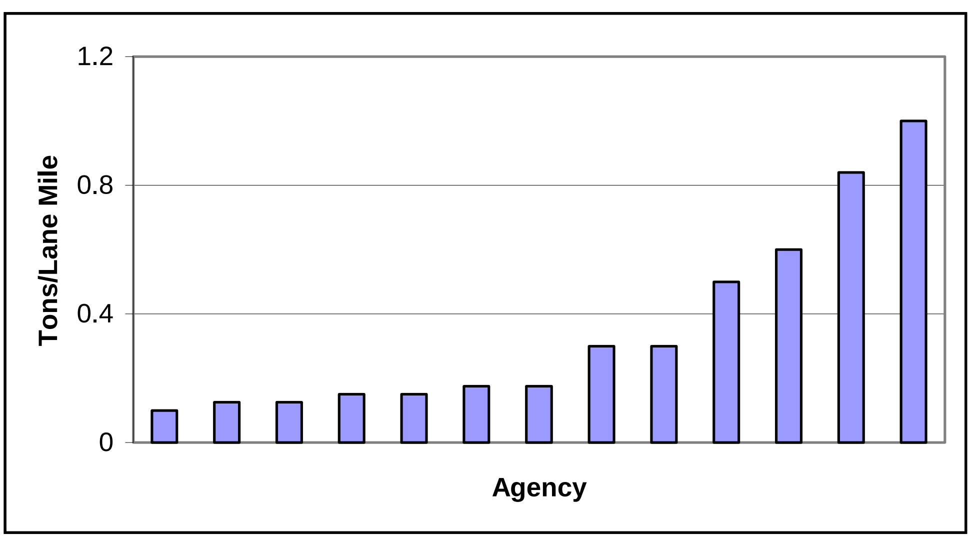

Figure 6 Deicing salt application rates from 2005 survey.

The survey asked the agencies whether any notable damage to tented pavement sections had been observed resulting from snow plowing. 17 percent of the survey respondents replied that damage could be attributed to plowing, in some cases resulting from snow plow operators using a higher down-pressure. 58 percent replied that no damage occurred at tented cracks from plowing operations.

The survey also asked how frequently the agency applied deicing chemicals to pavement surfaces. In most cases the response indicated that deicing chemicals were applied on an as-needed basis. One response noted that deicing would be applied twice during a snow event. Other respondents noted that treatment occurred prior to a storm. The typical response indicated that application occurred one to two times per week, depending on weather conditions and roadway type.

Chapter 3: Test Sites

Comments from the survey of Minnesota municipal, county, and state engineers were used to aid in selecting subject roads for the study of tenting. Since the survey results included surface type, treatments, and base as the most important contributing factors to tenting, this set of criteria was used for selecting subject roads in the tenting study:

- Bituminous surface, regarded to be more tent susceptible than concrete.
- Recycled or virgin aggregate base products were regarded as equally susceptible.
- Bituminous over concrete base.
- Transverse cracks, thermal or sawed.
- Filled versus non-filled cracks.
- Hills were reported more prone to tenting.

33 percent of the tenting survey respondents reported that they would like to be involved in the project. Project staff corresponded with survey participants and Mn/DOT districts to locate road segments conforming to the selection criteria.

Mn/DOT District 1, Materials Office, and Metro contributed to the location and selection process, and provided the following insights:

- US 169 (constructed 2001) HMA on aggregate and rubblized-concrete base. 2003 observed a few tented areas in sawed joints. 2004 observed number increased, with more severe tenting within the first days of below zero temperatures.
- Other projects (e.g. MN 53) with that same type of saw only construction have not tented.
- Unsawed portion of US 169 is not tented.
- This project used a PG 58-28 asphalt binder, the same oil has not tented on other projects like this project. Testing results of oil samples that were obtained during the project showed that the material met specifications.
- Possible relationship between precipitation and tenting: Bad tenting years may coincide with heavy rain events in November that are followed by freezing temperatures.

City of Eagan:

- Tenting was observed on Blackhawk Road.

Steele County:

- Observed some tenting on saw and sealed roads that should be investigated. Base materials were not believed to be the source of the problem. The pavement/saw & seals were about 7 years old and performed well until 2004-05. The road was seal coated when 2 years old and that is performing well.

City of Mankato:

- Tenting was observed at sites on the Madison Ave. hill, Stadium hill, Pleasant St. at Baker, and Balcerzak from Monks to Victory. By 2004 all of the locations had been overlaid with varying results.

Ramsey County:

- Tenting on Vadnais Blvd. from Edgerton to Rice.
- Silver Lake Rd. Silver Lane – I 694
- Centerville Rd. 96 to J
- Co. Rd. C TH 61 to Hazelwood
- Fairview Ave. Larpenteur to Roselawn

Possible steps to mitigate tenting:

- Schedule a thin mill and overlay using a higher PG oil.
- Seal sawed joints. 1/8-in. sawed joints open up wide in the winters and tent. Propose to do a reservoir saw on top of the 1/8" saw and not the route and seal type of joint seal here.
- Small mill (1 or 2-in.) at each transverse joint through bound pavement layers, and replace with blacktop. Patch in a couple of lifts to obtain compaction, leaving a little high so the traffic can beat it down. Just milling off the tops of the "tented" pavement would not be as good because when it settles it will then leave a dip at each location.
- Investigate exactly where the tenting is occurring with actual forensic cuts in the road.
    - Detailed analysis of the in place HMA, aggregate base and rubblized concrete material
    - Initiate an experimental joint/crack sealing projects on high tented areas with a number of cracks left unsealed, some sealed with route and seal and others crack filled with the AC crack filler, and monitor the results.

The list of subject roads was visited during January and February of 2005. Based on the selection criteria and safety concerns the project staff determined that the sites in Table 3 were appropriate for the needs of this study.

Table 3 Test Section in Winter Pavement Tenting Study.

Agency	Road	Transverse Crack Type				Terrain	Base	Subgrade
		Thermal	Sawed	Sealed	Unsealed			
Ramsey Co.	Silver Lk Rd	X	X	X	X	Flat to Rolling	Agg Base	
Ramsey Co.	Vadnais Blvd		X	X		Flat	Cl 7	
Mn/DOT	169	X	X		X	Rolling	Cl 6	Rubblized PCC
Mn/DOT	37	X			X	Rolling	Agg Base	PCC
Mn/DOT	53		X		X	Flat	Cl 6	Rubblized PCC
Steele Co.	CR 32		X	X		Rolling	Agg Base	
Steele Co.	CR 8		X	X		Flat to Rolling	Agg Base	
City of Eagan	Blackhawk Rd.	X		X		Flat to Rolling	Cl 7	
City of Mankato	Madison	X	X	X	X	Hill	Agg Base	
City of Mankato	Balcerzak	X		X		Flat	Agg Base	
City of Mankato	Stadium	X		X	X	Hill	Agg Base	

Chapter 4: Testing

This chapter summarizes the testing and measurements performed on the set of roadways in the winter pavement tenting investigation.

Testing and Sampling

A set of testing methods was produced based on the theories that the presence of deicing chemicals, sands, and crack sealing all influence pavement tenting. The methods were chosen mainly to gain information on winter conditions, when the test sites would likely show tenting.

Site surveys included making manual measurements, gathering surface samples, and documenting temperature. Two forensic projects were also included, each comprised of cutting excavation pits and sampling the surface and base materials. Other materials from the excavations were also sampled if found in the pits (e.g. silty materials or water). Additionally, longitudinal profile analyses were included.

Manual Measurements

In order to measure the vertical heaving effect of tenting on transverse cracks, manual measurements were taken using a steel rule and 2-ft straight edge near the crack. This process involved either measuring the tenting projected to a location 1-ft from the crack or measuring the cupping at the crack.

The horizontal motion of the pavement surface was determined by measuring the distance between PK nail sets that were placed on either side of the monitoring sites. Differential motion was calculated relative to the initial interval between nails. Measurements were taken using either a steel rule or micrometer. The severity of horizontal motion was also checked by inserting a 1.5 by 3.25-in. (38 by 83-mm) putty knife into the open transverse cracks.

Pavement temperature measurements were routinely obtained using a hand held Raytec thermometer or a FLIR infrared camera. Site conditions were documented with field notes and a digital camera.

Other Measurements

During the winter months between October 2005 and March 2007 a FACE dipstick was used to collect profile information for the test sites. Additionally, Mn/DOT Pavement Management personnel obtained profile measurements using high-speed pavement survey vans.

Sampling

During site surveys routine sampling was done at transverse cracks in order to collect material suitable for laboratory conductivity testing. Sample size was approximately one to two ounces. Samples were obtained from inside transverse cracks using an eyedropper. Surface samples were obtained using an eyedropper or putty knife.

In addition to the routine samples, forensic sampling included obtaining base material for conductivity and gradation analysis.

Table 4 Summary of LRRB 827 Activities on Subject Roadways.

Agency	Road	Conductivity Measurements	Vertical and Horizontal Measurements	Other Measurements	Maintenance Activities During Study
Ramsey Co.	CR 44	X	X	Temperature	
Ramsey Co.	CR 16	X	X	Profile, Temperature	
Mn/DOT	US 169	X	X	Profile, Temperature, Test pit and infrared camera, Tube suction on base material, base gradation	Seal cracks and transverse saw cuts, summer 2006
Mn/DOT	37	X	X	Profile, Temperature	Seal cracks and seal coat, summer 2006
Mn/DOT	53	X	X	Profile, Temperature	
Steele Co.	CR 32	X	X	Profile, Temperature	
Steele Co.	CR 8	X	X	Profile, Temperature	Chip seal, summer 2006
City of Eagan	Blackhawk	X	X	Profile, Temperature, 2 test pits and infrared camera, Moisture of material at bottom of tented crack. Mapping of reflected cracks at mill/overlay.	Mill and overlay at one test pit, summer 2005
City of Mankato	Madison	X	X	Temperature	
City of Mankato	Balcerzak	X	X	Temperature	
City of Mankato	Stadium	X	X	Temperature	

Testing and Monitoring Results

Figures 7 and 8 show relative horizontal and vertical motion observed at transverse cracks from the summer of 2005 to the spring of 2006. The technique used for gathering the measurements included setting a pair of PK nails into the pavement on either side of the crack and collecting measurements over time. Subject sites included roads with and without recurring winter pavement tenting. In several cases the relative motion with respect to the "baseline" observation resulted in negative values.

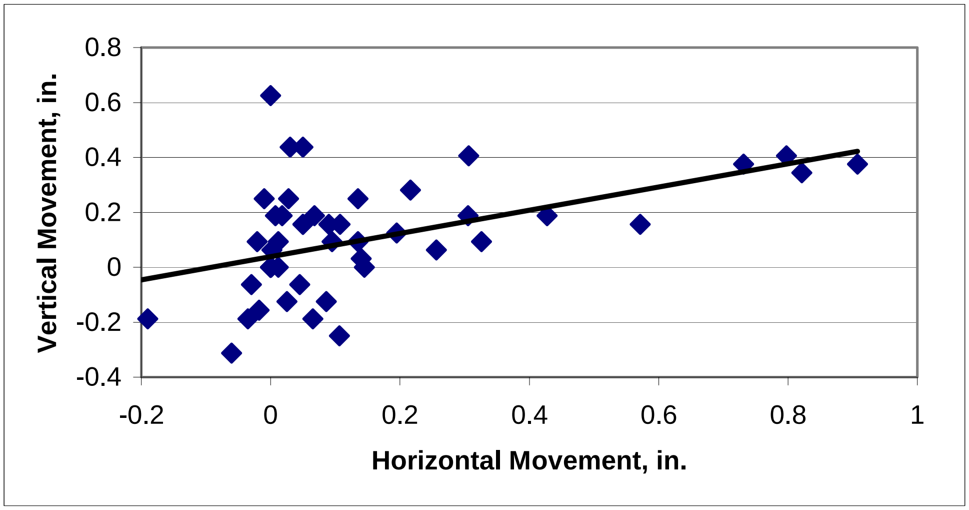

Figure 7 Tenting measurements of subject roadways.

For some locations tenting severity is related to the opening of transverse cracks.

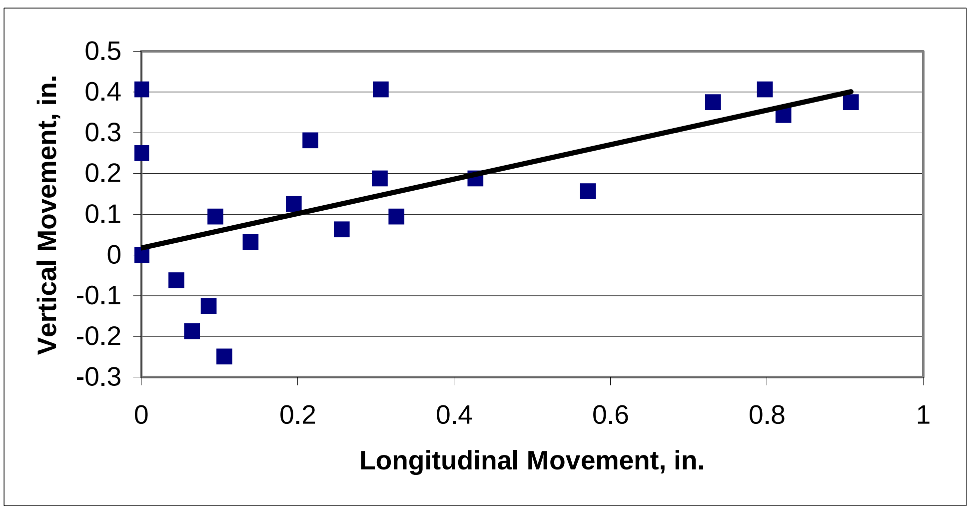

Figure 8 District 1 tenting measurements.

Test Pit Observations

A total of three test pits were excavated during the month of February 2005 with the aid of participating agencies. The City of Eagan Public Works Department excavated the following pits:

- one 4-in. HMA layer over aggregate base, and
- two 4-in. HMA layers over aggregate base.

A complete description of the aggregate base material was unavailable, but was said to contain some percentage of recycled Portland Cement Concrete. This anecdotal description was supported by the high degree of reactivity observed between the base material and a ten percent hydrochloric acid solution.

The Eagan pits were cut using a pavement saw and no water lubrication. The HMA block sections were removed undamaged using picks and pry bars. This cutting method enabled observation of the base material with little disturbance and moisture content evaluation. Base material was also collected for conductivity testing.

Figure 9 Frozen lens at top of test pit No. 1, located at the outer edge of the lane.

Figure 10 Ridge of fine material in the upper HMA layer of test pit No. 2, located at the centerline.

After HMA block removal, a ridge of fine, silty material was found just below the location of the tented cracks in each pit. The pit 1 ridge rested directly on the base, and was less pronounced than the ridge found between HMA layers in pit 2. It is hypothesized that in these cases the fines originated from degraded crack seal. Part of the pit 1 ridge may have been assimilated into the aggregate base.

The thermal image from pit 1 shows that a thermal contrast exists between aggregates in the zone below the HMA crack and the rest of the pit. The thermal image of pit 2 also shows the contrasts between the surface HMA, bottom HMA, and crack sealant material. This image also shows a thermal contrast present in the kerfs left by the pavement saw.

The recycled aggregate base material was removed for the purpose of gradation testing. However, gradation testing was abandoned since the dried samples were found to have particle segregation issues, containing a high percent of fines.

Inspection of the HMA blocks showed that some moisture was present along the crack edges and the bottom surface. Since the cutting operation used no lubrication, it was apparent that an amount of water had been present in the cracks, between HMA layers, and also in the base material.

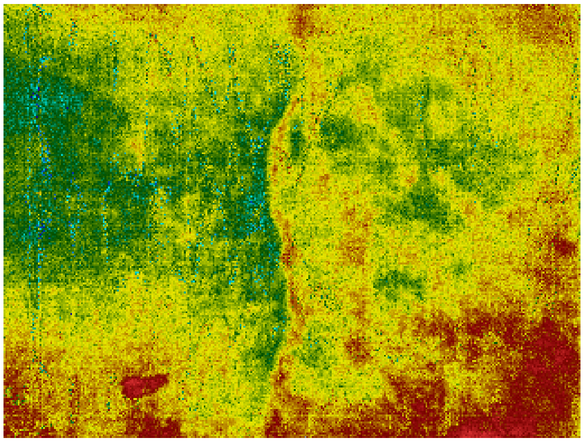

Figure 11 Thermal image of frozen lens in Pit No. 1.

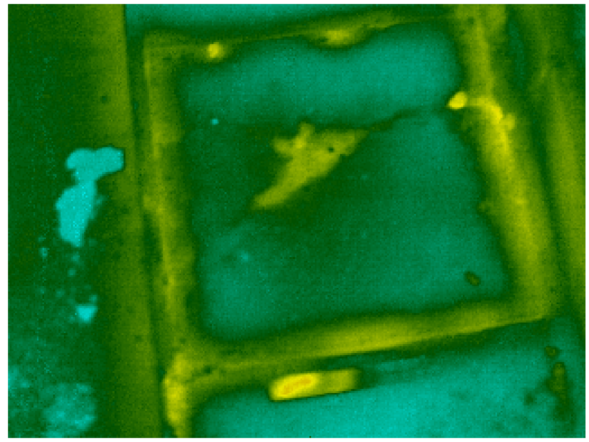

Figure 12 Thermal image of crack seal and HMA in pit No. 2.

Figure 13 Eagan pit No. 1 with moist regions highlighted.

Figure 14 Eagan pit No. 2 with moist regions highlighted.

The Mn/DOT District 1 Construction Office excavated one test pit on US 169. It will be referred to as the D1 pit. The section had 6.5-in. of sawed and unsealed HMA over a class 6 aggregate base, all above a rubblized concrete pavement. District 1 cut this pit using a pavement saw and water lubrication. Blocks of the HMA sections were removed undamaged using pry bars. Following HMA block removal it was observed that the test pit was 75 percent filled with water. The water was then removed from the pit in order to obtain samples and observations.

After water removal the base was sampled at various location for analysis of in-situ conductivity, and a quantity of material was removed for gradation and tube suction testing. Although the aggregate base was frozen solid, the wet cutting process had made it unlikely that a representative moisture content sample could be obtained.

The HMA layer did not appear to have uneven expansion due to moisture. However, a string line check of the bottom of the HMA layer (Figure 10) showed that the tented saw cut deviated 0.4 in. (10 mm) above the straight line.

Inspection of the D1 pit did not reveal ice lenses that were comparable to those found at the top of the Eagan base material. A thermal image of the aggregate base did indicate that non-homogeneous thermal properties existed in the region near the saw cut.

Figure 15 Mn/DOT D1 test pit over saw cut.

Figure 16 String line shows HMA tenting at bottom of D1 pit.

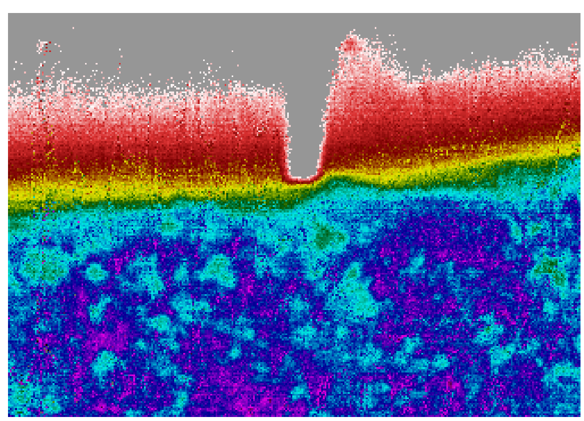

Figure 17 Thermal image of D1 pit showing HMA, wooden ruler, and base.

Conductivity Measurements

The concentration of deicing chemicals was studied at test pit excavations as well as other sites by using conductivity measurements. Conductivity is the ability of a material to conduct electrical current. A proportional relationship exists between ion concentration and conductivity value. Conductivity is defined in Equation 1:

$$k = \rho^{-1} = \text{length} / (R \cdot \text{area}) \qquad \text{Equation 1}$$

Where k is conductivity, ρ is resistivity, and R is resistance.

The standard SI conductivity unit is Siemens per meter (S/m). In this report conductivity values are shown in units of mS/cm.

Conductivity samples consisted of one to two ounces of solid or liquid material taken from the pavement surface, open transverse cracks, or the aggregate base. Measurements were conducted in the laboratory on undiluted samples if possible. When necessary, deionized water (conductivity approximately 10^{-3} mS/cm) was used for diluting samples. Measurement values were then adjusted proportionally in order to compensate for the dilution rate.

A total of 48 samples were obtained from subject roadway sites. Figures 18 and 19 show conductivity values for samples obtained from the sites.

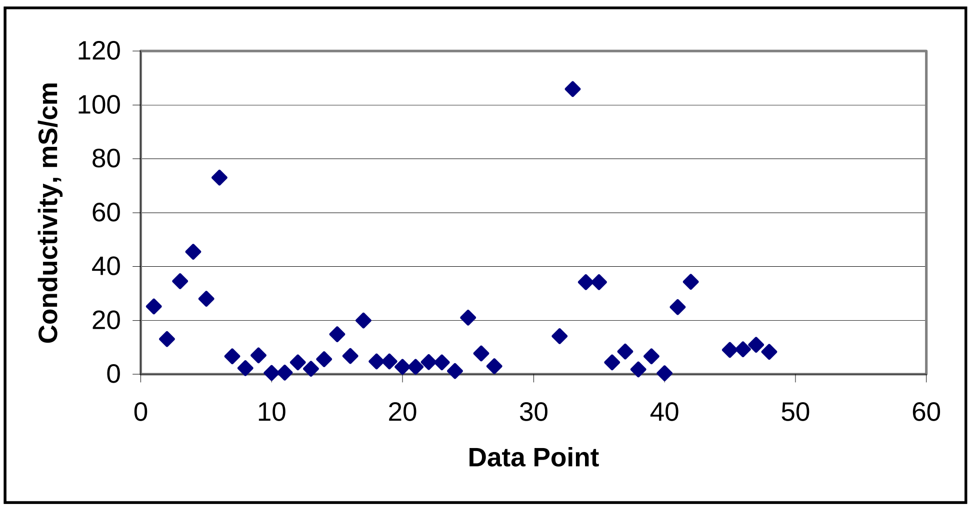

Figure 18 Conductivity measurements, multiple locations.

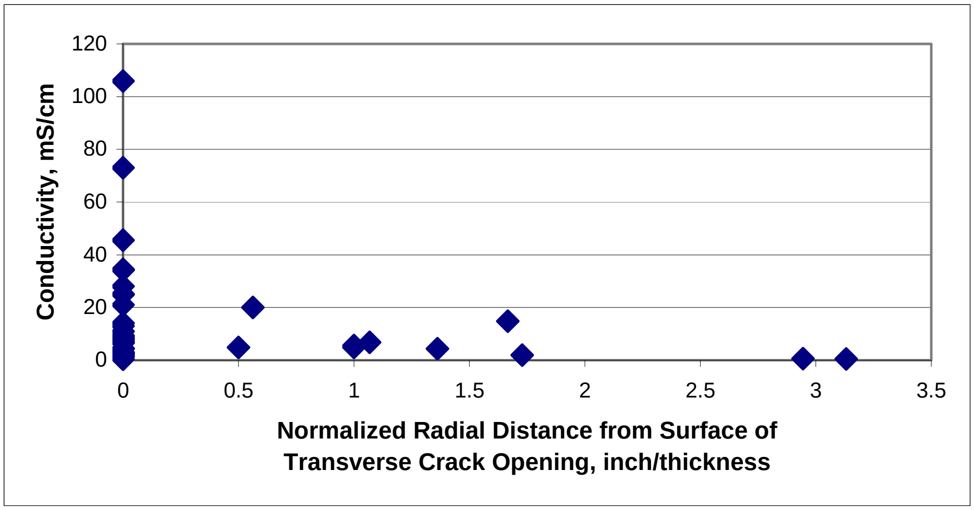

Figure 19 Conductivity data for 10 subject roadways, winters 2005-2006.

Table 5 shows conductivity measurement results for materials sampled from test pit excavations. The results are shown along with available moisture content data and distance from tented crack. In the case of the D1 pit the samples of base material obtained closest to the transverse saw joint were not frozen. This indicated the potential for a greater concentration of deicing chemicals. Aggregate base conductivity values are shown to range between 0.48 to 20 mS/cm. These values are approximately 10 and 400 times the conductivity of tap water.

Table 5 Conductivity Data – Test Pits.

Test pit	Sampling location	Description	Conductivity, mS/cm	Distance from Crack *	Moisture Content, %
No. 1	Top of base.	Frozen base material.	5.6	1	18.4
No. 1	Top of base.	Sediment ridge material above base	20	1	6.0
No. 1	Top of base.	Base material.	14.8	1.7	9.3
No. 2	Top of base.	Frozen base material.	6.8	1.1	
No. 2	Top of base.	Sediment ridge material above base	4.8	1	4.1
No. 2	Between overlay and original AC.	Sediment ridge material below overlay	4.8	0.5	5.3
D1	Pavement surface.	Melted snow and fine sediment.	7	0	NA
D1	Base mid-depth (3-in.).	18" from saw cut. Frozen base material.	0.48	3.13	NA
D1	Top of base.	18" from saw cut. Frozen base material.	0.65	2.94	NA
D1	Top of base.	6" from saw cut. Unfrozen base material.	4.4	1.36	NA
D1	Base mid-depth (3-in.).	6" from saw cut. Unfrozen base material.	2	1.73	NA

(*) Normalized radial distance from crack surface = $\sqrt{\text{depth}^2 + \text{longidudinal distance}^2} \div \text{pavement thickness}$

Figures 20 and 21 show differences in deicing chemical concentration occurring throughout the base structure. The figures use samples obtained at various depths and distances from the transverse crack. Figure 20 shows the conductivity conditions (with respect to depth and horizontal distance from the transverse crack) that occurred during excavation of test pit D1. Figure 21 shows various conductivity measurements obtained at test pits No. 1 and 2, and plots them with respect to depth. Figures 20 and 21 show that it is possible to see how differences in deicing chemical concentration occur throughout the base structure using samples obtained at various depths and distances from the transverse crack.

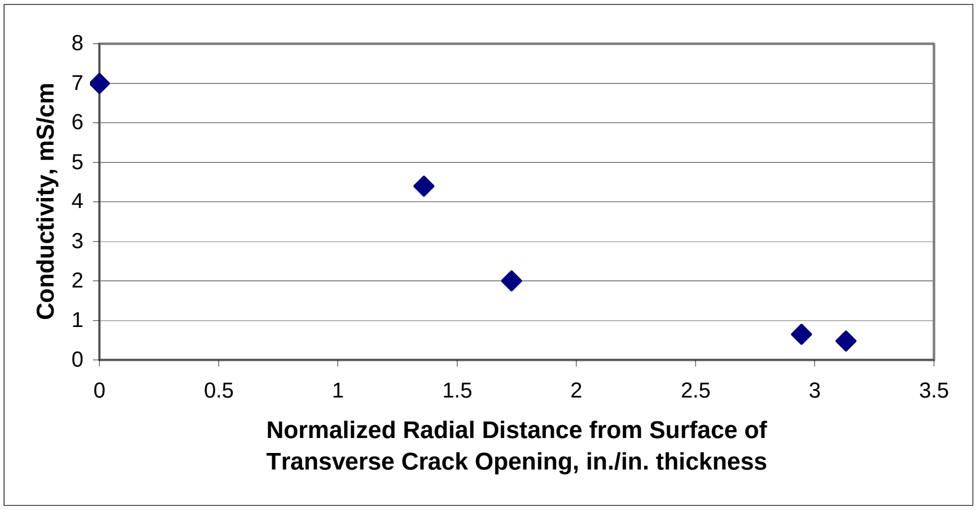

Figure 20 D1 pit: conductivity vs. normalized distance.

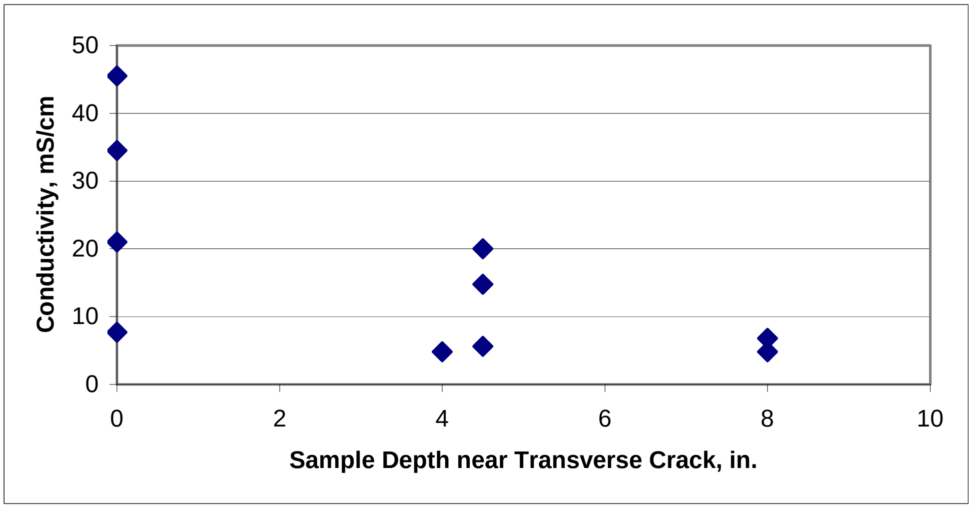

Figure 21 Conductivity vs. depth data at pit No.'s 1 and 2.

Tube Suction Testing and Results

A gradation analysis and tube suction testing was performed on the base material that was removed during the D1 test pit excavation. The gradation analysis results plotted in Figure 22 show that the size distribution of the material conforms to Mn/DOT standard specification 3138, Class 6.

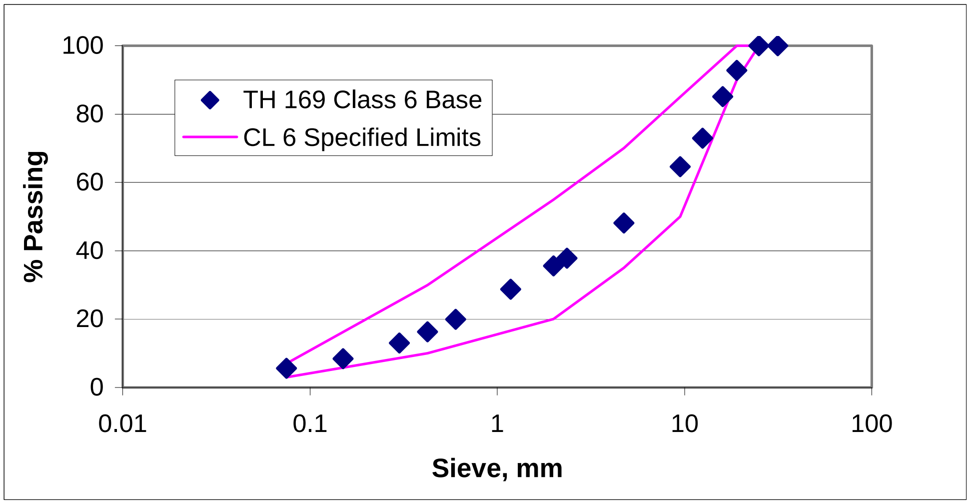

Figure 22 Gradation of US 169 class 6 base.

Tube suction testing included measurement of conductivity and dielectric values over time at various moisture contents. Tube suction testing was performed on unbound, compacted Class 6 specimens prepared at optimum moisture in 6 x 12-in. cylinders. The cylinders contained small holes near their base that were intended to allow the movement of water. Conductivity, dielectric, and moisture measurement proceeded after the prepared specimens were dried to zero percent moisture and then placed in a shallow water bath.

Figure 23 is a plot of moisture monitoring results from the tube suction test, with the D1 material shown as TS39** on the legend. The labels TS29 – 36 are for test results from tests of other Class 6 aggregate base materials. The other materials were unrelated to the winter pavement tenting study, and are included only for reference purposes.

Figure 23 shows that during the tube suction test the moisture content of the D1 specimen increased to a value over six percent. Figures 24 to 26 plot the measurements performed during the tube suction test. Comparison of the four charts shows that the peak conductivity occurs near six percent moisture and does not coincide with arrival at the maximum moisture content.

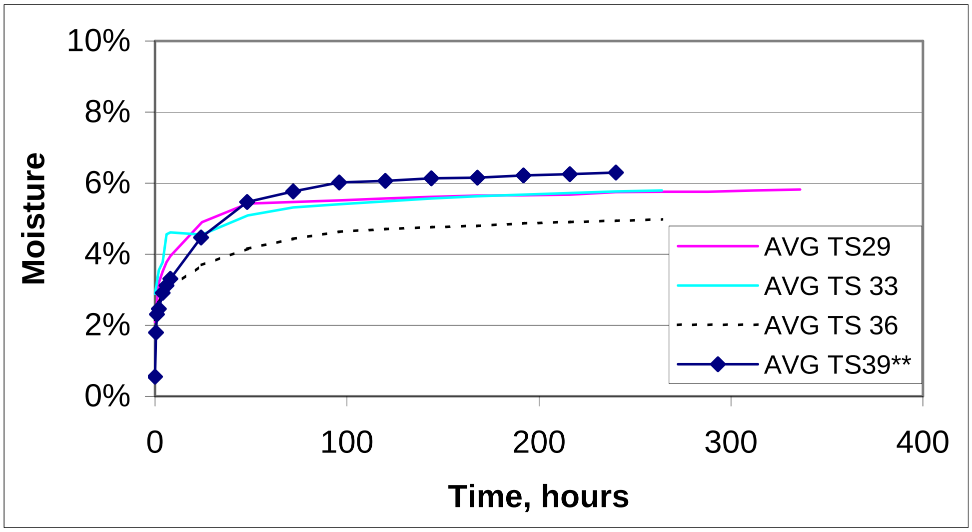

Figure 23 Tube suction test of US 169 Class 6 base: moisture vs. time.

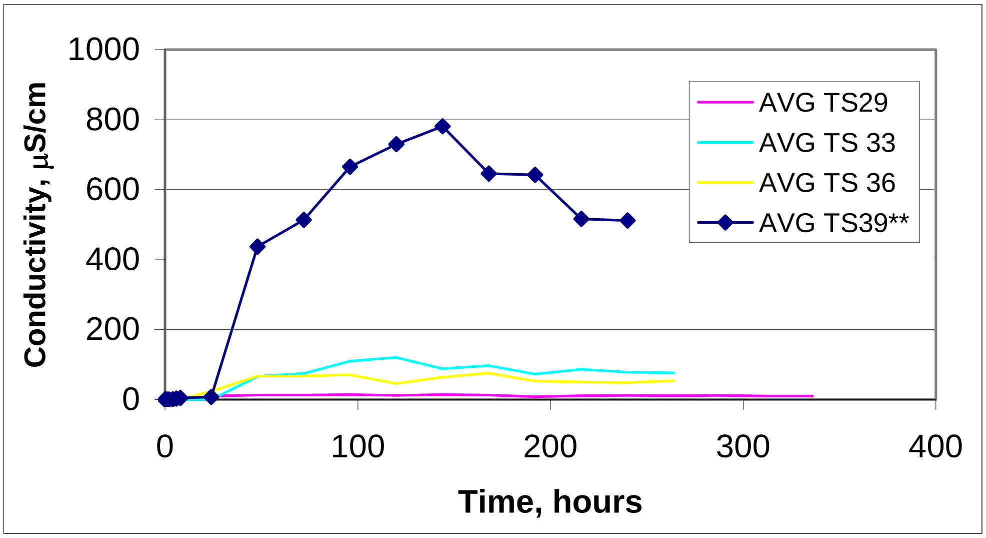

Figure 24 Tube suction test of US 169 Class 6 base: conductivity vs. time.

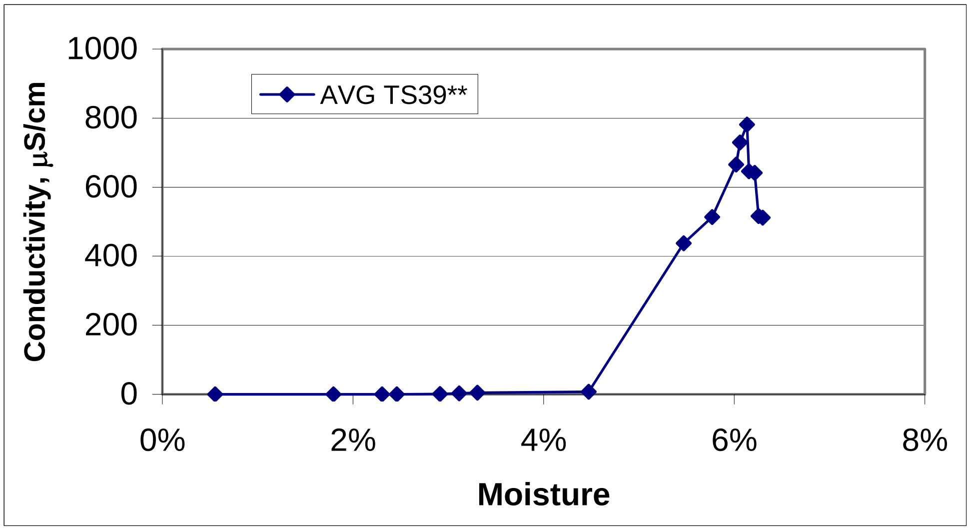

Figure 25 Tube suction test of US 169 Class 6 base: conductivity vs. moisture.

Figure 26 shows the dielectric values obtained during the tube suction test. Dielectric is an indicator of volumetric water content. Comparison with Figure 23 shows agreement with dielectric measurements reaching a plateau at approximately 50 hours. The dielectric plateau coincides with approximately 5.5 percent moisture.

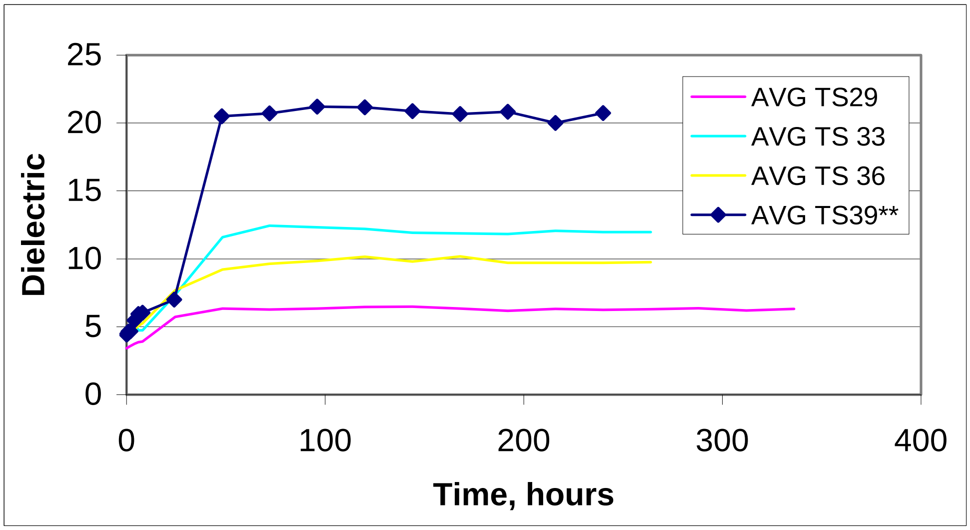

Figure 26 Tube suction test of US 169 Class 6 base: dielectric vs. time.

Dipstick Measurement and Results

After one winter of observation the project had investigated the horizontal and vertical motion present in pavement surfaces during winter. However, there was yet no description of the pavement surface between tented cracks, nor a measurement of the effect on the ride quality of the subject roads.

During the subsequent winters of 2006 and 2007 the project used a FACE ® dipstick to measure the shape of the road surface between tented cracks. The dipstick included a sensor that measured elevation change. The sensor was contained in a metal case mounted to a pair of swiveling footpads. The circular footpads, 2.5 in. in diameter, were separated by a distance of 12 in. A 32-in. handle provided the operator a means to move the apparatus by rotating on each of the footpads in turn. The device can automatically collect a reading upon reaching a condition of repose.

Each dipstick data point represents a change in elevation from the previous point. Research staff opted to use the individual readings obtained in the region near the tented crack as a severity indicator.

All of the dipstick graphs are plotted using data that have been conditioned so the average vertical value of each run is equal to zero. Figures 27 through 31 plot data obtained on Steele County's 40-ft saw and seal construction.

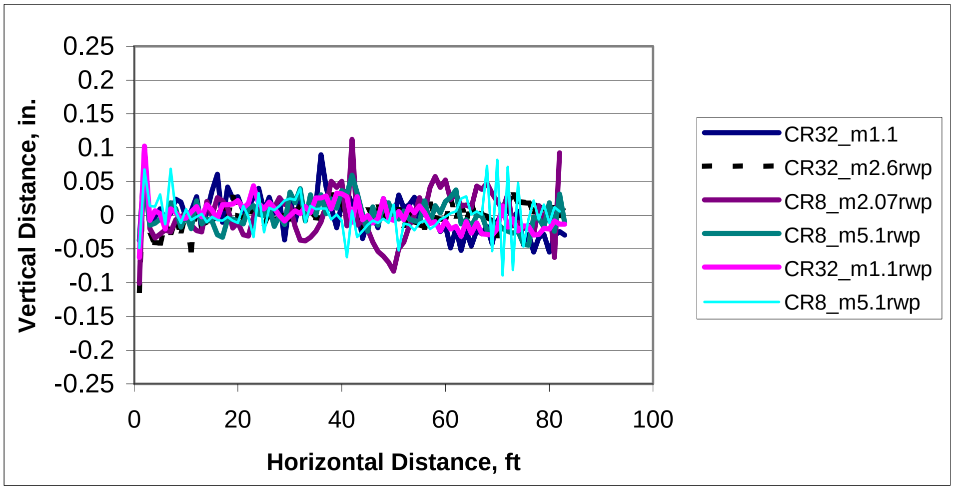

Figure 27 Steele County dipstick survey, 3/2/2006.

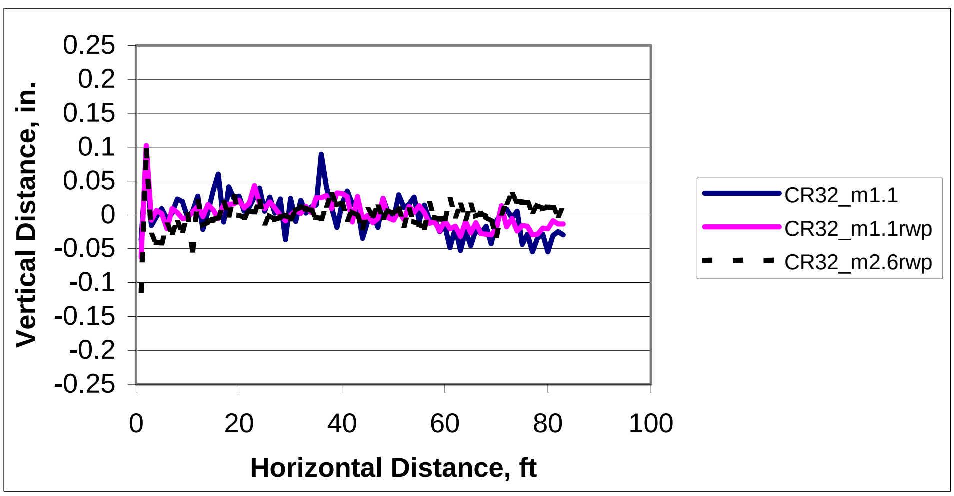

Figure 28 Steele County dipstick survey, 40-ft saw and seal, 3/2/2006.

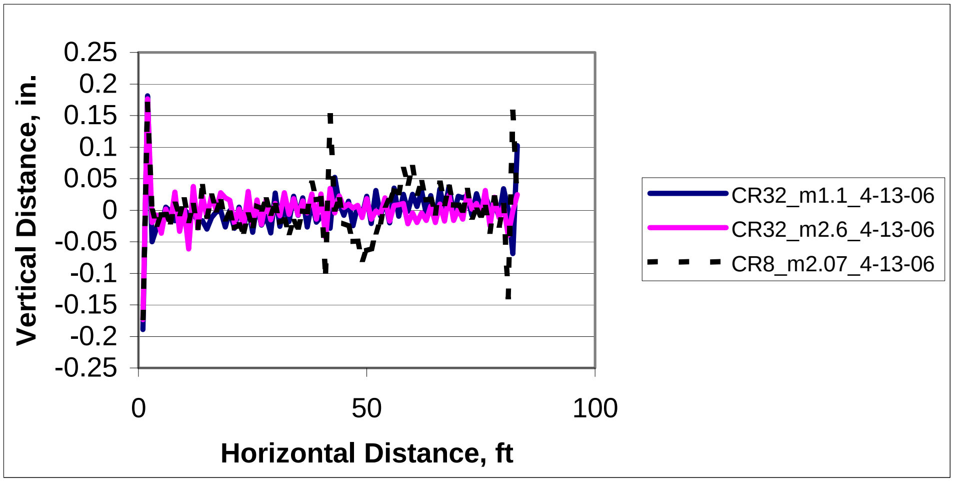

Figure 29 Steele County dipstick survey, 40-ft saw and seal, 4/13/2006.

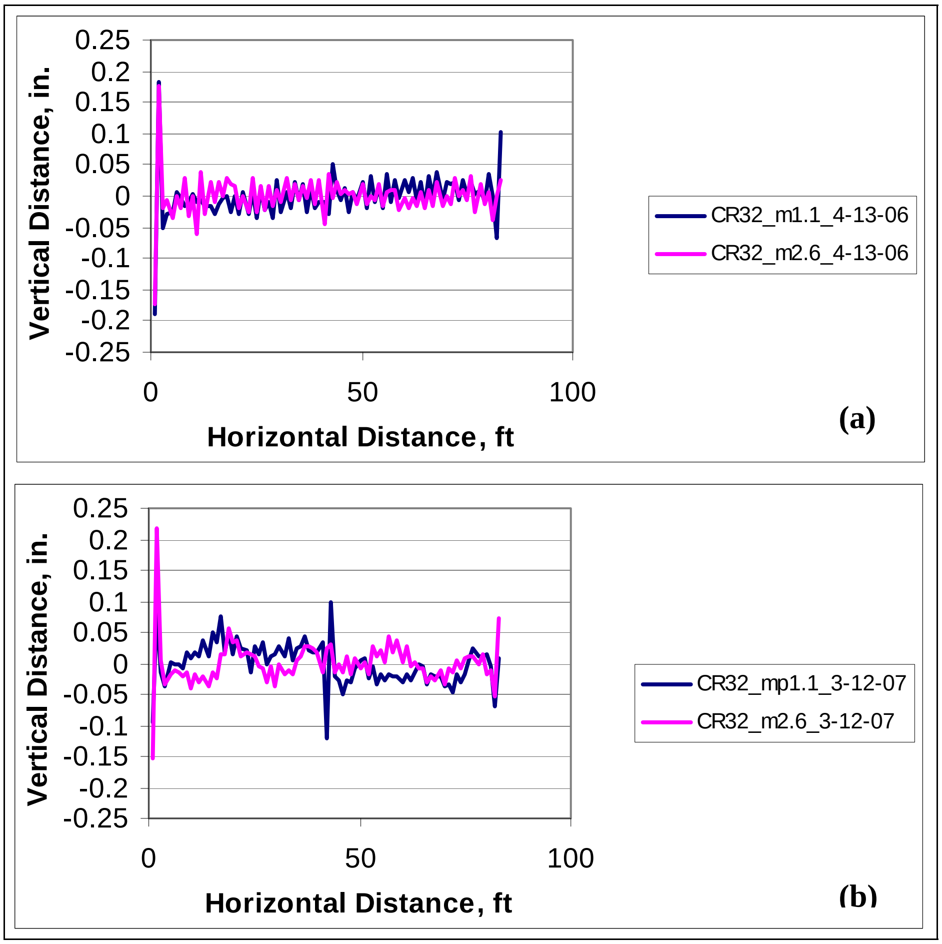

Figure 30 a – b Yearly winter dipstick surveys of 40-ft Saw and Seal HMA, RWP.

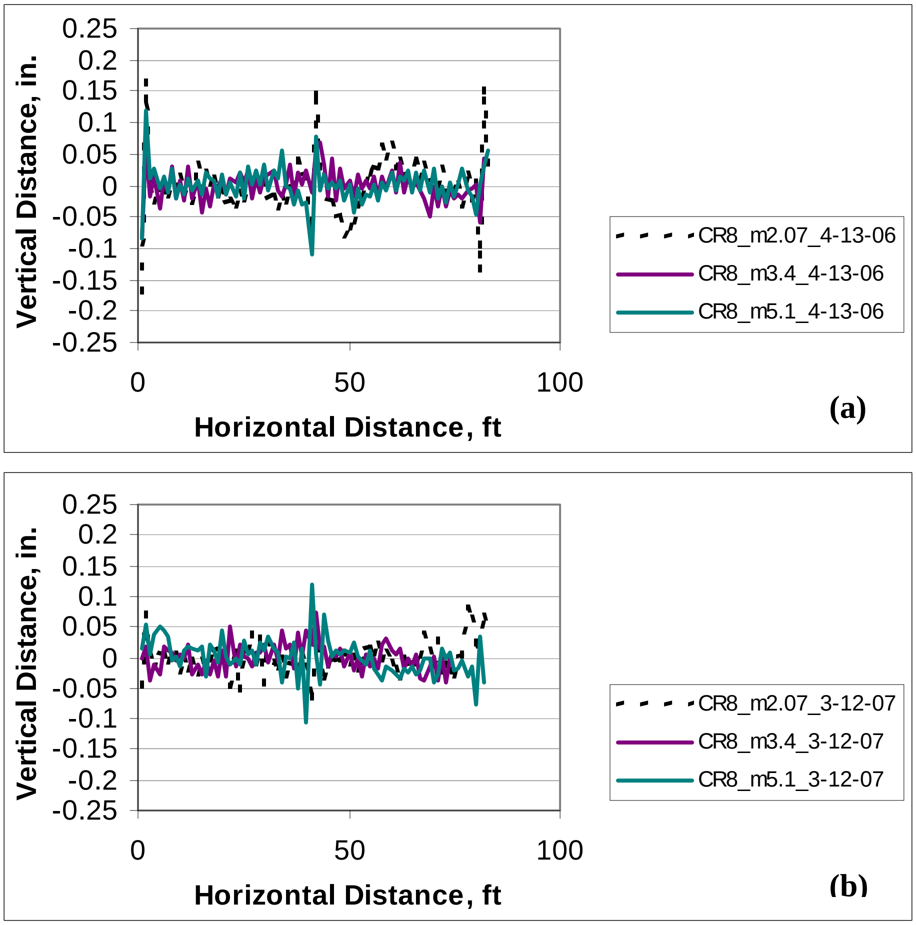

Figure 31 a, b – Yearly winter dipstick surveys of 40-ft Saw and Seal HMA, RWP.

Figures 32 and 33 plot profiles of thermal and reflected cracks near test pits No. 1 and 2 on City of Eagan streets.

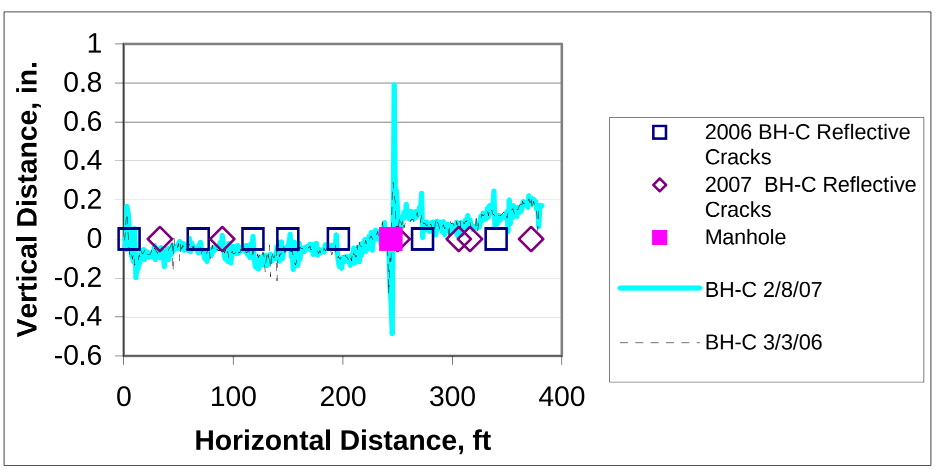

Figure 32 Yearly dipstick surveys of a mill and overlay treatment at test pit No 2 (BH-C).

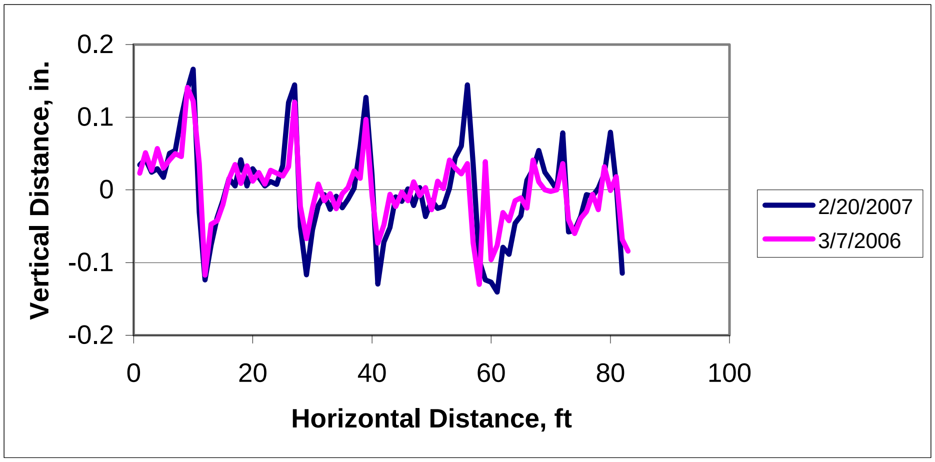

Figure 33 Dipstick surveys of winter tenting near test pit No 1.

Additional dipstick surveys were performed on saw and seal construction in Ramsey County and also on unsealed sawed construction and unsealed thermal cracks in Mn/DOT District 1. Plots of these surveys are similar to Figures 22 through 28, and are omitted for brevity.

High Speed Profiler Results

During the winters of 2006 and 2007 ride performance data was collected by the Mn/DOT Pavement Management Office. This data included high-speed profiler surveys of the following roadways:

- Steele CSAH 8 from Owatonna to county highway 12
  - surveyed 2006 only
  - chip seal in 2006
- US 169 from milepost 350 to 360
  - north and southbound, both lanes
  - northbound right shoulder
  - saw cuts sealed in 2006
- MN 37 from milepost 24.7 to 28
  - crack seal and seal coat in 2006
- US 53 from milepost 42 to 48

Figures 34 to 38 show plots of simulated profilograph traces based upon the high-speed profiler data. The traces illustrate the presence of recurring tented sawed joints on US 169, lack of such feature on US 53, and the presence of less regularly spaced tented thermal cracks on MN 37. Each plot is of a randomly selected 0.1-mile section.

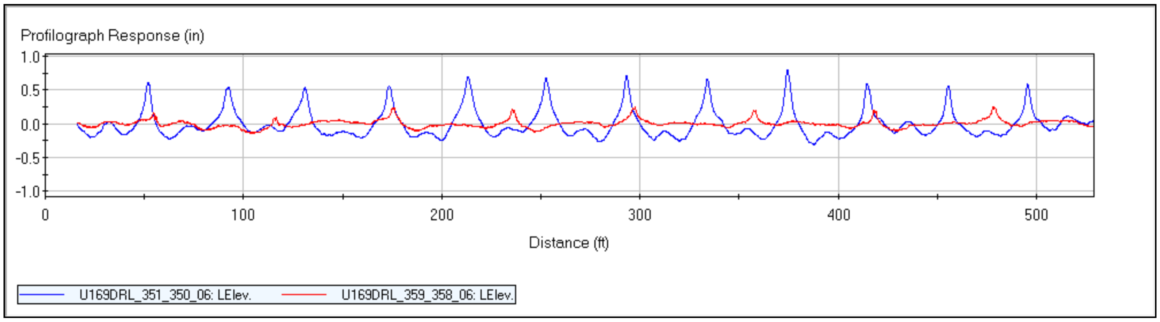

Figure 34 Profilograph trace of US 169 sections, winter 2006.

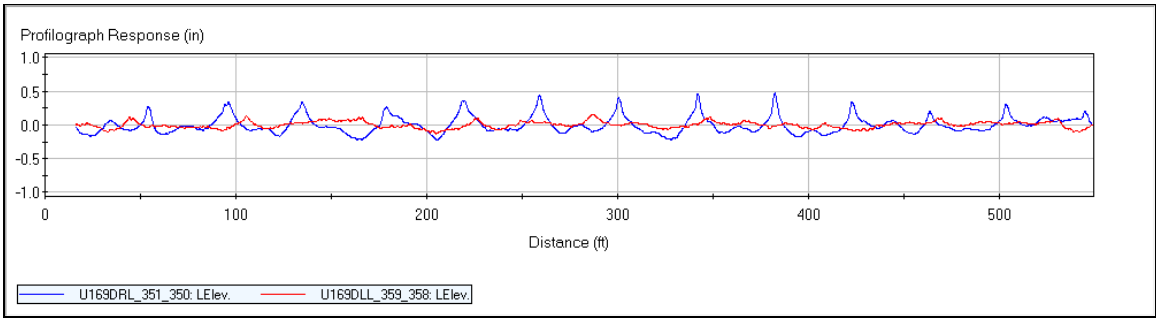

Figure 35 Profilograph trace of US 169 sections, winter 2007.

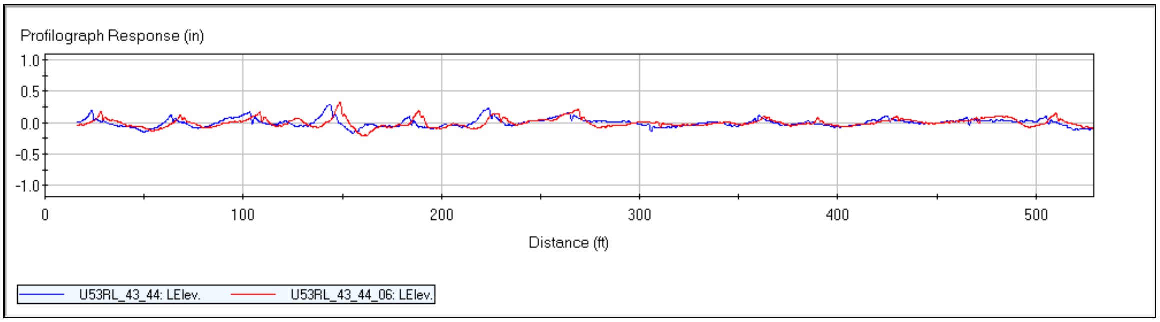

Figure 36 Profilograph trace of US 53 mile 43, winters 2006 and '07.

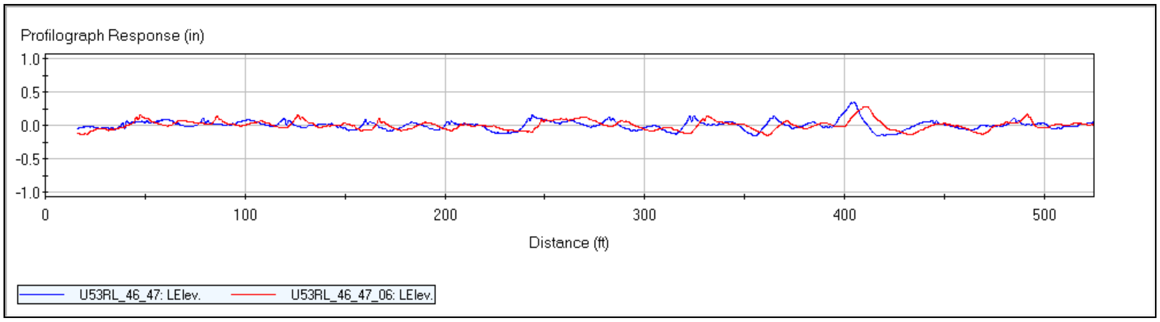

Figure 37 Profilograph trace of US 53 mile 46, winters 2006 and '07.

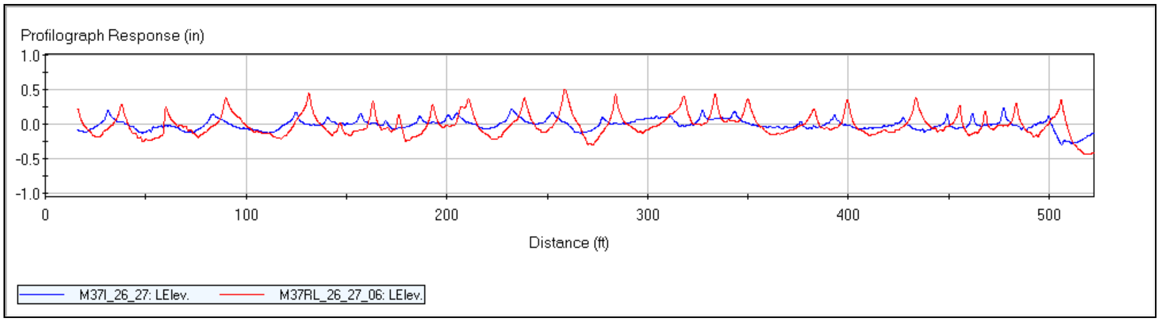

Figure 38 Profilograph trace of MN 37 mile 26, winters 2006 and '07.

Before-after comparisons of the above figures show the impact of maintenance treatments on winter ride quality. Ride performance will later be analyzed using the International Roughness Index (IRI, inches/mile).

Table 6 contains 2006 and 2007 average IRI values for each 1-mile section.

Table 6 Average IRI: 2006 and 2007 Subject Roadways.

Roadway	**Direction**	**Lane**	**2006 winter IRI, in./mile**	**2007 winter IRI, in./mile**	**2006 summer maintenance action**
All sections	-	-	133.8	114.7	-
Control Section US53	Increasing	Right	84.6	74.6	None
MN37	Increasing	NA	236.1	194	Crack seal and seal coat
US169	Decreasing	Right	110	78	Seal all sawed joints
US169	Increasing	Right	-	72.1	None
US169	Increasing	Shoulder	151.1	143.8	None

Chapter 5: Data Analysis

Seasonal Effects on Asphalt Pavement

A set of measurements was obtained during periods when roads were deemed likely to produce tenting. Site surveys included making manual measurements, gathering surface samples, and documenting temperature. Two forensic projects were also included, each comprised of cutting excavation pits and sampling the surface and base materials. Other materials from the excavations were also sampled if found in the pits (e.g. silty materials or water). Additionally, longitudinal profile analyses were included.

Analysis included examining statistical relationships for tenting severity based on temperature conditions and the presence of deicing chemicals, as well as the effect of various maintenance activities on tenting severity.

Analysis of Field Measurements

Chapter 4 presented data for relative horizontal and vertical motion observations at transverse cracks. Subject sites included roads varying according to tenting history and severity. Baseline measurements were established during warm weather conditions for comparison with measurements obtained during the winter months.

Some change was observed at each site during the winter observations. Pearson correlation analysis shows that as the temperature decreased both the transverse crack opening and the tenting increased, as expected. The data also showed that a positive relationship existed between vertical movement (tenting) and longitudinal movement (transverse crack opening). The magnitude of the correlations was approximately the same between temperature, longitudinal movement, and vertical movement for the general data set.

Table 7 Pearson Coefficients for Localized Tenting Measurements.

All subject sites – Correlations	Temperature	Longitudinal Movement
Longitudinal Movement	-0.4426	1
Vertical Movement	-0.5021	0.4787

A subset of the localized heave data showed a higher correlation between vertical tenting and longitudinal opening of transverse cracks. That set included the subject roads in Northern Minnesota: US 169, MN 37, and US 53. The condition at these sites included both unsealed sawed and unsealed thermal cracked pavements. Crack openings ranged from zero in. during summer to nearly one in. during winter. Likewise, tenting ranged from zero in. during summer to approximately 0.4 in. during winter.

Conditions were similar for the sites on US 53 and 169, where old PCC pavement had been rubblized and covered with Mn/DOT specification Class 6 base material. A sawed – unsealed asphalt layer had been constructed over the Class 6.

The sites on MN 37 included open, working thermal cracks that had developed in years prior to the study. It is interesting to note that for the data obtained in this region of the state longitudinal movement of the open cracks was better correlated to tenting than to temperature. At the same time, it appears that change in temperature may influence tenting more than longitudinal movement on roads of this type.

Table 8 Pearson Coefficients for Northern MN Tenting Measurements.

Northern MN – Correlations	Temperature	Longitudinal Movement
Longitudinal Movement	-0.2791	1
Vertical Movement	-0.5293	0.8589

Characterization of Tented Condition

As noted in chapter 1, previous work had been done by the Mn/DOT Pavement Management unit to characterize tenting on northern Minnesota roads. As part of their analysis a minimum threshold of 0.1-in. was established to classify whether an arbitrary crack measurement should be classified as tented.

The same criterion was used to classify the data set of dipstick measurements. The results are presented below; showing that tented conditions existed for much of the study on these subject roads. The values in this table were obtained by examining dipstick profiles that were effectively conditioned to a one-foot rolling straight-edge by subtracting the run average from each value. Local maximums were selected from the conditioned data in regions near known transverse cracks in order to determine the presence of tenting.

Table 9 Dipstick Evaluation of Tented Condition.

Date	Road	RP	Tenting	Condition
2/8/2006	37	27	0.19	Tented
4/11/2006	37	27	0.09	
3/8/2007	37	27	0.14	Tented
2/8/2006	53*	46n	0.21	Tented
4/11/2006	53*	46n	0.14	Tented
3/8/2007	53*	46n	0.13	Tented
4/11/2006	169	351n	0.06	
3/8/2007	169	351n	0.11	Tented
2/8/2006	169*	352xs	0.21	Tented
4/11/2006	169*	352xs	0.1	Tented
3/8/2007	169*	352xs	0.18	Tented
2/8/2006	169*	359s	0.06	
4/11/2006	169*	359s	0.05	
3/8/2007	169*	359s	0.07	
3/3/2006	Blackhawk	Cochrane	0.17	Tented
2/8/2007	Blackhawk	Cochrane	0.17	Tented
3/7/2006	Blackhawk	Kyllo	0.14	Tented
2/20/2007	Blackhawk	Kyllo	0.17	Tented
4/17/2007	Blackhawk	Kyllo	0.15	Tented
3/2/2006	Steele 32*	1.1	0.09	
4/13/2006	Steele 32*	1.1	0.18	Tented

3/12/2007	Steele 32*	1.1	0.09	
3/2/2006	Steele 32*	2.6	0.03	
4/13/2006	Steele 32*	2.6	0.04	
3/12/2007	Steele 32*	2.6	0.03	
3/2/2006	Steele 8*	2.07	0.11	Tented
4/13/2006	Steele 8*	2.07	0.15	Tented
3/12/2007	Steele 8*	2.07	0.07	
3/2/2006	Steele 8*	5.1	0.06	
4/13/2006	Steele 8*	5.1	0.12	Tented
3/12/2007	Steele 8*	5.1	0.12	Tented
3/3/2006	Vadnais*	EB	0.13	Tented
4/17/2007	Vadnais*	EB	0.16	Tented
3/3/2006	Vadnais*	WB	0.2	Tented
4/17/2007	Vadnais*	WB	0.14	Tented

(*) ASPHALT LAYER CONTAINS SAWED JOINTS.

Ride data was collected on the northern Minnesota subject roads during 2006 and 2007. The data was analyzed with ProVal software, simulating the trace that would be obtained for a 10-ft straightedge. The traces were shown previously in figures 33 – 37. The ProVal plots reinforce the use of a 0.1-in. vertical tenting threshold.

Table 10 compares the results of high-speed van data with dipstick data obtained during the same time frame.

Table 10 Comparison of Tented Condition from Dipstick and Ride Data.

Date	Road	ProVal 10-ft simulation	Dipstick Condition
2006	37	Tented	Tented
	53	Tented, occasional	Tented
	169, 351n	Tented	
	169, 352x s		Tented
2007	37	Tenting diminished	Tented
	53	Tented, occasional	Tented
	169, 351n	Tented	Tented
	169, 352x s	Tenting diminished	Tented

Analysis of Factors Contributing to Tented Condition

Road Salt

The presence of salt was tested by measuring the conductivity values for samples obtained from the subject roadways. Conductivity sampling consisted of one to two ounces of solid or liquid material that were taken from the pavement surface, within open transverse cracks, or from the aggregate base.

Sampling style varied somewhat depending upon the openness of the crack and presence of snow melt. Measurement was conducted in the laboratory on undiluted and diluted samples, if necessary. Measurement values were adjusted to reflect dilution rate.

It was found that conductivity values fluctuated about the mean value of 15.5 mS/cm. When normality was assumed the coefficient of variation for conductivity measurements was 133 percent.

Figure 39 is a plot of the data set of conductivity values. Figure 40 shows conductivity versus the standard normal z-score. It is apparent that the data is skewed to the positive, and the skewness was calculated to be approximately 2.7. Adjusting to a log-normal distribution in Figure 41 improves the skewness to approximately -0.27, with the resulting log average equal to approximately exp (0.88) mS/cm = 7.6 mS/cm. This value may be more representative of the center of the overall data set.

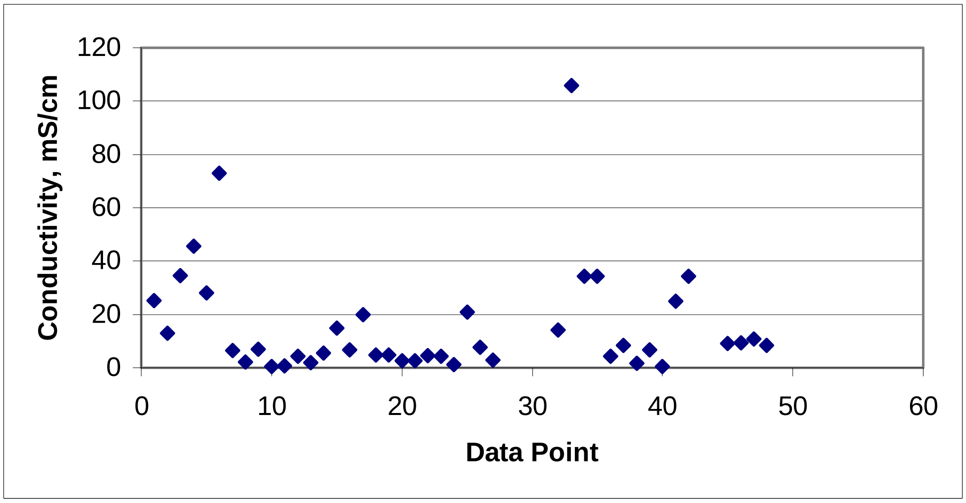

Figure 39 Conductivity measurements from subject roads.

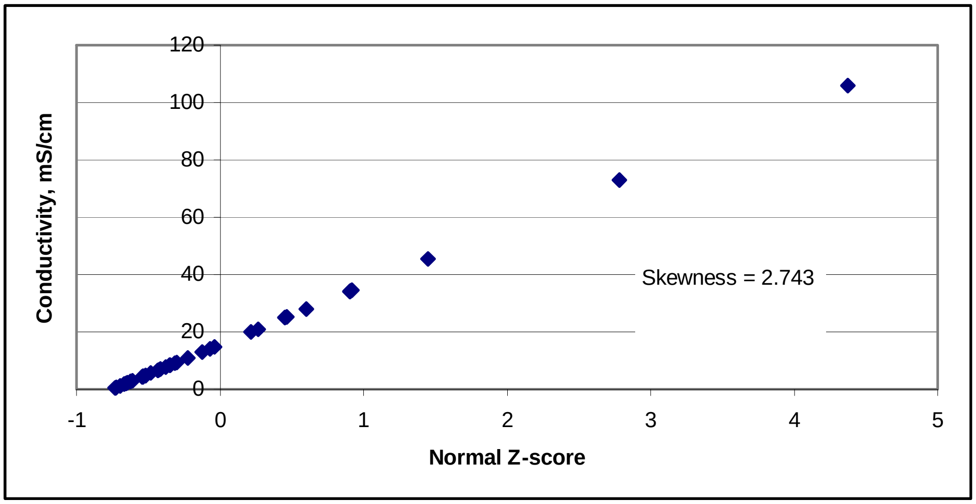

Figure 40 Normal skewness of conductivity values from subject roads.

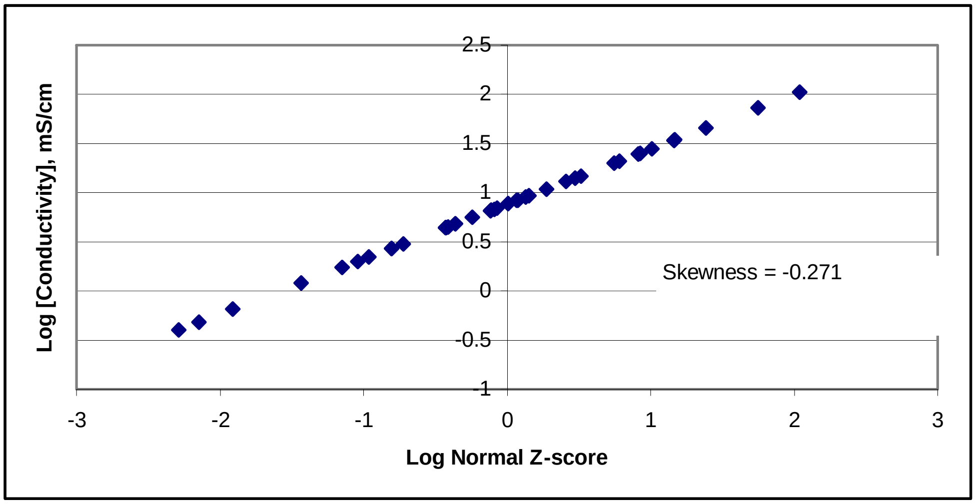

Figure 41 Log-normal skewness of conductivity values from subject roads.

Road Salt in Test Pits

The base material was sampled from test pits cut near tented cracks in US 169 near Buhl, MN and Blackhawk Road in Eagan, MN. Tenting was equally severe at both locations when the test pits were excavated.

Corresponding conductivity values for the samples of base material were plotted versus location in chapter 4. Blackhawk Road generally exhibited conductivity levels above the general data set average of 7.6 mS/cm, reaching a maximum value nearly six times the general average. However, the data from US 169 had a maximum of merely 7 mS/cm. The discrepancy between measurements and observed tenting severity may be explained by noting two differences between the samples. The Blackhawk Road site had been in service longer than the US 169 site, and more importantly the sawing method introduced lubricating water into the base material at US 169 but not at Blackhawk Road.

One other difference to note was that the base materials on Blackhawk contained silt-like particles from recycled PCC, and the US 169 site was a clean Class 6 with roughly 5 percent fines.

Regardless of site differences it is possible to see that the road salt contamination tends to decrease with depth and distance from the transverse crack. Additional work performed on the US 169 base material included a tube suction test and gradation. The tube suction test measures the conductivity in a prepared specimen at various moisture contents.

Moisture content was not sampled from the test pit on US 169 due to the mild flooding caused by the introduction of lubricating water. However, moisture was evaluated for the dry-sawn Blackhawk Road pits and found to be between 9 and 18 percent in the base material, as shown in Table 11.

Tube suction testing showed that the US 169 base material achieved a maximum moisture content near 6 percent after a testing period of approximately 100 hours. It may also be reasonable to assume that because of gradation structure the base present at US 169 had a lesser affinity for moisture in comparison with the material at Blackhawk Road. Conductivity at 100 hours was approximately 700 mS/cm. The maximum conductivity was near 800 mS/cm, and was achieved at approximately 150 hours. These values are approximately 100 times greater than the average of the general data set.

Table 11 Moisture in Blackhawk Road Test Pit.

Location within pit	Description	Conductivity, mS/cm	Radial distance from crack **	Moisture Content, %
Top of base.	Frozen base material.	5.6	1	18.4
Top of base.	Sediment ridge material above base	20	1	6.0
Top of base.	Base material.	14.8	1.7	9.3
Top of base.	Frozen base material.	6.8	1.1	Not taken
Top of base.	Sediment ridge material above base	4.8	1	4.1
Between overlay and original AC.	Sediment ridge material below overlay	4.8	0.5	5.3

(**) NORMALIZED TO PAVEMENT THICKNESS.

Moisture and Maintenance Relationship to Tenting

The tube suction data suggests that base materials may accumulate large amounts road salt, even in relatively new pavement construction. The accumulation presents a potential problem since salts have the ability to attract moisture, and are known for their hygroscopic characteristics.

The following examples from tenting project data effectively serve as a case study on the influence of maintenance on base course moisture and pavement tenting.

1. Blackhawk Road mill and bituminous overlay.

During the summer of 2005 the City of Eagan conducted a mill and overlay project on approximately 380 ft of Blackhawk Road, including the site of the Cochrane test pit. The sections were also crack sealed. For the purpose of this case study the location of the Kyllo test pit was selected as the control section.

It was found that during the winter of 2005-06 initial reflective cracking occurred at the rate of 23 reflected cracks, a total of 202 lineal feet. A subsequent crack survey during the winter of 2006-07 showed reflective cracking had progressed to 48 cracks, a total of 470 lineal feet.

At this time dipstick and hand measurements were obtained over the transverse cracks in these subject roads. It was found that the 2005-06 tenting measurements on the mill and overlay were approximately 51 percent of those on the control section. Measurements obtained after a one-year period showed there was no difference between treated and control sections. Figure 31, in chapter 4, included dipstick data along with location of cracks in 2006 and 2007 and Table 12 includes comparative tenting data.

Table 12 Blackhawk Road Test Case.

Roadway	Direction	Lane	2006 winter tenting profile, in.	2007 winter tenting profile, in.	2006 control ratio	2007 control ratio	2005 summer maintenance action	Winter tenting % improvement	Control ratio % improvement
Control Section Blackhawk-Kyllo	SB	-	0.221048	0.21006	**1**	**1**	None	5%	0%
Blackhawk-Cochrane	NB	-	0.112164	0.2099	0.5074	1	Mill and overlay	-87%	-97%

2. Route and seal of sawed bituminous pavement

During the summer of 2006 the state of Minnesota conducted a route and seal project on the sawed sections of US 169 between Virginia and Chisholm, MN, including the site of the Buhl test pit. For the purpose of this case study an untreated similar sawn-unsealed section of US 53 was selected as the control section.

It was found that prior to treatment, during the winter of 2005-06, International Ride Index (IRI) measurements on US 169 sections averaged 130.6 in./mile. During the winter of 2006-07 the IRI had dropped to an average of 98 in./mile, an improvement of 25 percent. Table 13 contains comparative ride data.

Table 13 Northern Minnesota Test Case.

Roadway	Direction	Lane	2006 winter IRI, in./mile	2007 winter IRI, in./mile	2006 control ratio	2007 control ratio	2006 summer maintenance action	Winter IRI % improvement	Control ratio % improvement
All D1 sections	-	-	133.8	114.7	1.6	1.5	-	14%	3%
Control Section US53	Increasing	Right	84.6	74.6	**1**	**1**	None	12%	0%
MN37	Increasing	NA	236.1	194	2.8	2.6	Crack seal and seal coat	18%	7%
US169	Decreasing	Right	110	78	1.3	1	Seal all sawed joints	29%	20%
US169	Increasing	Right	-	72.1	-	1	None	NA	NA
US169	Increasing	Shoulder	151.1	143.8	1.8	1.9	None	5%	-8%
All US 169			130.6	98	1.8	1.9		25%	-8%

Figure 42 shows a point-by-point comparison of the unsealed IRI from 2006 next to the 2007 sealed IRI and Figure 43 shows a distribution of IRI improvement along segments of the route and seal project.

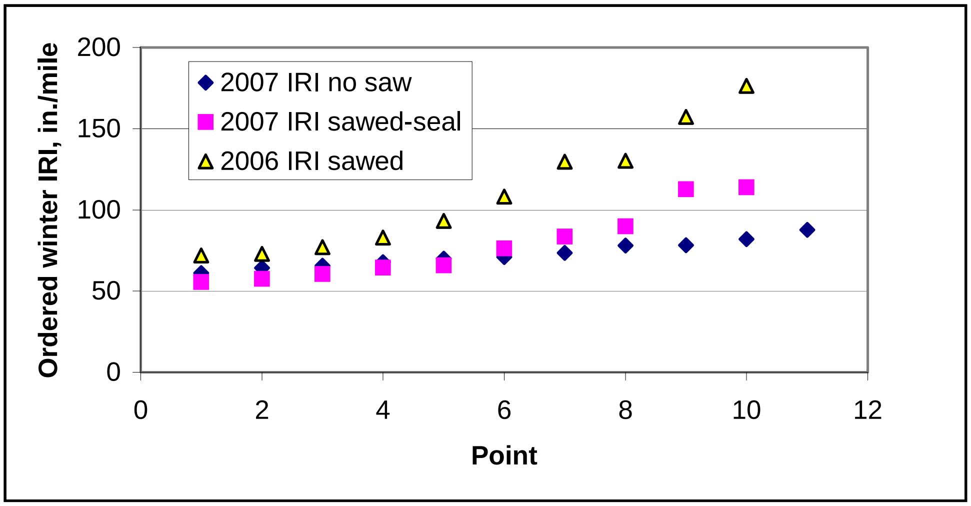

Figure 42 US 169 winter IRI comparisons for three treatments.

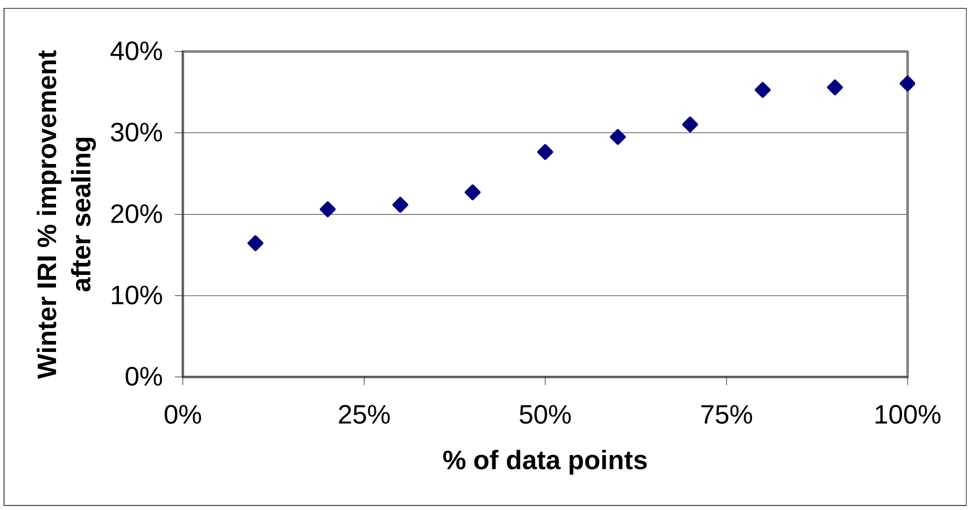

Figure 43 Winter IRI improvement following seal of saw cuts, US 169.

3. Crack seal and seal coat on bituminous pavement

During the summer of 2006 the state of Minnesota conducted a crack seal and seal coat project on the sections of MN 37 west of Gilbert, MN. For the purpose of this case study an untreated sawn-unsealed section of US 53 was selected as the control section.

It was found that prior to treatment, during the winter of 2005-06, IRI measurements on MN 37 sections averaged 236.1 in./mile. During the winter of 2006-07 the IRI had dropped to an average of 194 in./mile, an improvement of 18 percent.

Figure 44 plots 2007 IRI versus 2006 IRI for the three subject sections in northern Minnesota. All of the treated sections showed some improvement. The unimproved shoulder of US 169 did not appear to experience an IRI decrease.

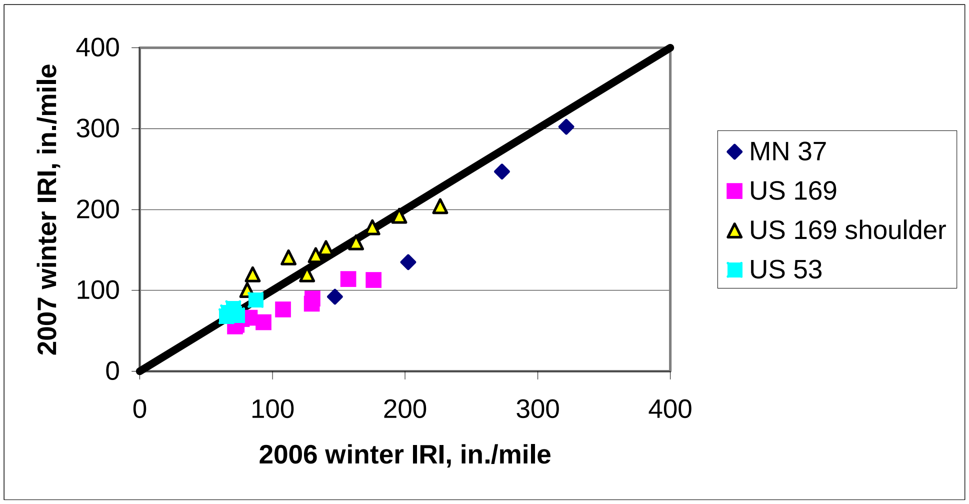

Figure 44 Winter IRI, 2007 vs. 2006.

Chapter 6: Conclusions

Measurement of base materials below tented cracks showed that the concentration of deicing salts was highest near crack openings and decreased with depth and distance from the crack. The presence of salt in the base, combined with an open crack, can promote the retention and accumulation of moisture in the pavement structure near the crack.

Measurements showed that crack sealing can reduce roughness and height of tented cracks. The data suggests that by crack sealing a tented road there may be a benefit of reducing tenting roughness from 20 to 35 percent during the first year.

From field observations it was found that the extreme vertical heave trend of tented cracks was approximately 50 percent of the change in longitudinal crack opening. Longitudinal profiles of tented cracks show that heave may occur several feet from the crack opening. Therefore, when maintenance crack sealing is performed on roads having wide cracks that are prone to tenting, every effort should be made to install the most elastic and durable sealant material available. It is also recommended that agencies perform cold weather inspections of sealant performance to become aware of adhesive or cohesive failures that may not be apparent during warm weather.

Mill and overlay treatment was successful in eliminating tenting during the first year. However, it was observed that reflective cracking occurred during the first winter on a mill and overlay pavement structure that was prone to tenting. In order to reduce the likelihood of tenting recurrence it is recommended that agencies investigate the moisture sensitivity as well as the level of salt contamination of the base material prior to overlay. It is also recommended that full depth reclamation or contaminated base removal is considered as a treatment alternative per Kestler's [6] recommendations.

References

1. Mn/DOT Pavement Management Unit, D-1 *Tented Crack Study*, Report#: MnDOT/OM-PM--2004-02. (Maplewood, MN: Minnesota Department of Transportation Office of Materials, Maplewood MN, May 2004).

2. N. Fradette, G. Dore, P. Pierre, and S. Hebert. "Evolution of Pavement Winter Roughness". Transportation Research Record (2005), No.1913, p.137-147.

3. G. P. Gonzalez, and K. Moo-Young, *Transportation Applications Of Recycled Concrete Aggregate*, FHWA State of the Practice National Review, (Durham, NH: Recycled Materials Resource Center, 2004).

4. G. Dore, J. M. Konrad, and M. Roy, "Role of Deicing Salt in Pavement Deterioration by Frost Action." Transportation Research Record (1997), No.1596, p.70-75.

5. Mn/DOT Report, *The Effectiveness of Crack Sealing in Solving Tenting in Flexible Asphalt Pavements,* (St. Paul, MN: Minnesota Department of Transportation, 1997).

6. M. A. Kestler, A. S. Krat, and G. E. Roberts, *Tenting of Highway Pavements; Test Program and Discussion of Causes and Mechanisms*. (Concord, NH: New Hampshire Department of Transportation, 2000).

7. A. K. Sharma and J. A. McIntyre, "Reflective Cracking and Tenting in Asphaltic Overlays". Transportation Research Record (1991), No.1300, p.22-29.

Appendix A

Survey of Highway Engineers:

Investigation of Winter Pavement Tenting

Appendix A - Tenting Survey

Question 1: Does your department find winter tenting occurring in local pavements?

37.5% *Yes* 62.5% *No*

a. *Your estimate of tenting distress:*

Tenting Distress	**Percentage Of Local Network**			
	0 – 25%	25 – 50%	50 – 75%	75 – 100%
Low	26% response	6% response	3% response	9% response
Moderate	18% response	12% response		
High	26% response	0% response		
(25 respondents selected 34 separate total responses.)				

Question 2: Comments/descriptions of cracking associated with tenting:

- I haven't noticed any tenting.
- Write back if you have any questions or if I can be of help.
- We have not experienced a serious tenting problem although about ten years ago we had a lot of rain in the late fall and then we had immediate record cold temperatures. Many of our roads tented then and stayed that way all winter.
- Tenting occurs most in areas of transverse cracks.
- Jackson County does not have a problem with tenting.
- Mille Lacs County does not have a tenting problem.
- Rise of Surface @ crack in pavement.
- We have an aggressive route and seal and seal coat program that reduces this.
- Minor problem
- NA
- Minor problem
- Salted hills worst. Salted arterials next; some residentials for no observed reason.
- We aren't experiencing tenting at this time in our community.
- Generally, transverse thermal cracks. System is crack sealed but tenting seems to be associated with crack seal failures. Appears to be symptomatic of certain types of base materials?
- Our worst sections were bituminous over concrete most of which have been replaced in the past 5 years. The remaining section of BOC is due to be replaced this summer.

Question 3: Would you be willing to discuss pavement designs that appear either tenting susceptible or resistant with project staff?

50% Yes 21% No

OR,

Please list any pavement structures that stand out as tent-resistant or tent-susceptible.

	Structure			
Tent Susceptibility	**Surface**	**Base**	**Subbase**	**Subgrade**
☐ Yes	Bituminous (7) General material (2)	Gravel (1) Class 5 (1) Class 6 (1) Recycled bit (1) Recycled concrete (1) Bituminous (1) Concrete (1) General material (2)	Class 7 (1) Granular (1) Aggregate base (1) General material (3)	Heavy (1) Sand (3) General material (2)
☐ No	Concrete (1)	Granular (1)	Granular (1)	
☐ Both		General material (2)	General material (2)	General material (1)
Total (from 24 respondents)	38% yes 4% no 0% both	38% yes 4% no 8% both	25% yes 4% no 8% yes	25% yes 0% no 4% yes

Comments:

- The only area of tenting distress on local roads has been on concrete streets resurface with bituminous overlay.
- We have fairly low binder content in our base and sub base and have not seen the tenting effect. We have seen our shoulder gravel remain soft and that may be due to the higher binder content in the shouldering material.

Question 4: Crack maintenance strategy

Technique	**Used Locally**		**Effectiveness Against Tenting**		
	Yes	No	Poor	Moderate	Good
Saw, unsealed	0%	25%	4%	0%	0%
Crack Filling	46%	4%	4%	13%	4%
Saw and Seal	29%	21%	4%	8%	13%
Rout and Seal	67%	4%	0%	13%	29%

Comments:

- From my experience in visiting other agencies, crack filling does prevent tenting.
- Crack maintenance is important to preserve pavement.
- Have resorted to maintenance overlays since mostly on hillsides.

Question 5: Winter maintenance strategy

Deicing product:	% deicer	% sand	Comments:
CaCl	75	25	below 20F we add some sand
CaCl	8 gallons/ton		Priority Routes
Clearlane Treated salt	100	0	
NaCl	10	90	if cold we will go up to 30% on salt.
NaCl	10	90	After Ice Storm the proportion is closer to 40/60
Rock salt	20	80	
Salt	10	90	
Salt	25	75	
Salt	70	30	
Salt	100		
Salt	100		
Salt	50-100	0 - 50	
Salt and sand	10	90	
Salt and sand	10	90	
Salt and sand	15	85	
Salt and sand	20	80	
Salt and sand	50	50	residential neighborhoods
Salt and sand	75	25	Priority Routes
Salt and sand	50-100	0-50	50/50 blend salt/sand. 30% of routes salt only.
Salt and sand and brine	10 - 20	80 - 90	We have one route at 100% salt when temps allow.
Salt or brine; some recent corn derivative.	100		
Salt, Caliber 2000	20% salt, 7 gal 2000	80	
sand	20 - 22	78 - 80	
Seal coat chip seal is also recycled into all our recycled sand		50	50% chips

Application Frequency

- After snowfall
- As needed (10 responses)
- As needed 2 times a day per event
- As needed during storm events

- As needed on intersections, curves and hills
- Average 45 times per winter season
- Ice storms and compaction depends on temps.
- Once after plowing then spot treatment
- Prestorm
- Weekly (average)

Rate	Method	Equipment
10 cy/8 miles.	Back spreader.	Trucks.
1200 lbs/mile.	Sander (non calibrated).	Tandem and single axel.
140 - 600 lbs/22-lane mile.	Premixed in stockpile with MgCl.	Tailgate sanders.
200 - 400 tons/lane mile.	Tailgate spreader/spinner.	Trucks.
2000 lb/mile.		Auger w/ spinner sander.
250 lb/lane mile.	Standard spreader.	Standard sander spreader.
300 lb/lane mile.	Truck Sander/spreader.	Tandem/single axel trucks. Swenson spreader, Falls plows.
40 gallons/lane mile.	Streamed out LCS - 10% corn salt with 90% brine solution.	Low pressure electric pump with 6 inch spaced nozzles on pvc spray.
400 - 800 lbs/lane mile depending on event.	Computerized spreaders, calibrated annually.	Component Tech and Force America.
400 lb/mile.	Spinners.	Tandems w/pre wetting tanks.
500 lb/road mile.	Auger and spinner.	Snowplow truck, box, sander.
600 - 800 lbs/mile.	Sander.	Dumps.
600 - 800 lbs/mile.	Sander.	Dumps.
600 lbs/lane mile.	Truck with sander.	Truck with sander.
unknown		Truck with sander.
VARIABLE depending on conditions.	Spinner sander.	Monroe sander.
VARIABLE depending on conditions.	Spread on centerline with equipment retro fit on plow trucks.	Class 33 and Class 35 plow trucks.
VARIABLE Depending on Conditions.	Tailgate sanders.	Trucks.
Where needed.	Sander (broadcast)	Trucks.
	We sand hazard areas only. Stop signs intersections, etc.	Truck with sander.

a. *Is there notable damage to tented sections from snowplowing?*

17% Yes 58% No

- I don't think we have any tented cracks.
- (damage) Where graders are used w/ a higher down pressure.
- My staff doesn't think we experience this in McLeod.
- Roads where we have observed tenting: Centerville Rd. from 96 - J; Co Rd. C from TH61 - Hazelwood; Silver Lake Rd from Silver Lane - I694; RECYCLED BIT BASE at Fairview
  Ave from Larpenteur Ave - Roselawn; Vadnais Blvd. From Edgerton - Rice;
- We do not (except in extreme) salt our roads. We normally salt/sand our intersections and hills.
- It's my opinion that deicing chemicals may contribute to tenting phenomenon but not necessarily the major factor. We use deicing on all our State highways but they do not all react with the tenting phenomenon. I think it has to do with the ability of water to be able to move vertically and/or horizontally out of transverse cracks. If it is trapped, it will eventually freeze and create the ice lense that pushes the pavement up creating the tented bump. The tented crack is fairly uncommon in our district and in part due to our abundant granular subsoils I think. At the same time, I have never seen any soil that is drainable once frozen solid.

Question 6: Does your department have an interest in participating in a study of tented cracks?

33% Yes 54% No