EVALUATION OF PRECUT TRANSVERSE CRACKS FOR AN ASPHALT CONRETE PAVEMENT IN INTERIOR ALASKA (MOOSE CREEK – RICHARDSON HIGHWAY)

FINAL PROJECT REPORT

by

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16. Abstract

Road-width thermal cracks (major transverse cracks) are perhaps the most noticeable form of crack-related damage on AC pavements throughout colder areas of Alaska. The main objective of this study is to recommend design strategies and construction practices aimed at controlling thermal cracking in AC pavements. In this report, literature review summarizes selected items of the engineering literature directly relevant to precutting of pavement-type structures and control of thermal cracking in general. Crack surveys and data collection were conducted at the test sections in an AKDOT&PF resurfacing project to compare various precut strategies (variations of cut spacing and depth), with the locations of natural major transverse cracks both before and after construction. Laboratory testing and numerical analysis were also presented to provide basic data about the physical properties of the AC and help explain some of the observed characteristics associated with natural thermal cracking.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

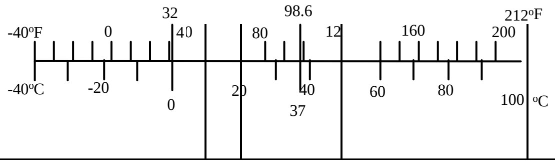
Note: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
ºF	Fahrenheit temperature	5/9 (ºF-32)	Celsius temperature	ºC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

These factors conform to the requirement of FHWA Order 5190.1A *SI is the symbol for the International System of Measurements

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
ºC	Celsius temperature	9/5 ºC+32	Fahrenheit temperature	ºF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi



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EXECUTIVE SUMMARY

Low temperature cracking is one of the most prevalent pavement distresses found in Alaska and cold areas of other northern states. The low temperature cracks are extensive enough that a significant portion of DOT Maintenance and Operations budget is allocated to sealing and associated work required to repair them. Until new technologies may someday eliminate cracking, considerable funds will continue to be spent on crack sealing and associated work. Innovative and cost effective approaches and techniques to preserve and maintain existing highway systems are needed. Precutting of thermal cracks in asphalt concrete pavements has provided promising results in controlling pavement degradation usually associated with natural thermal cracking, according to the field observations in Alaska (since 1984) and Minnesota (since 1969). However, a systematic approach has not been developed to implement optimum application of this technique in AC pavements, especially when the thermal cracking actually involves both the AC layer as well as the underlying aggregate.

During the 2012 construction season, transverse crack precutting was done within a 1-mile section of AKDOT&PF’s Richardson Highway Mile 340 to 346 project. The experiment was composed of four subsections: subsection 1 which is the control section without saw cuts; subsection 2 which has 17 cuts of each of the three depths (0.5”, 1.0”, and 1.5”) with each 25’ apart; subsection 3 which has 11 cuts of each of the three depths (0.5”, 1.0”, and 1.5”) with each 40’ apart; and subsection 4 which has total 28 cuts (7 at a depth of 0.5”, 10 at 1.0” and 11 at 1.5”) and the cuts are located over the cracks in the asphalt that was replaced (the preconstruction natural thermal cracks).

Crack surveys and data collection were conducted at the test sections to compare various precut strategies (variations of cut spacing and depth), with the locations of natural major transverse cracks both before and after construction. Field data consisted of photos (obtained in 2012, 2013, and 2014) and crack location surveys (done in October 2013 and March 2014). Before 2012 construction, the number of natural transverse cracks in all four subsections was similar. In just the two years since construction, the crack counts in subsections 1, 2, and 3 had actually increased by 77%, 23%, and 17% over the preconstruction number, respectively. Only the natural transverse crack count in subsection 4 remained lower than the preconstruction number—17% lower than the count prior to the repaving job. The subsection 4 precut design approach appears quite superior to those used in

subsections 2 and 3. In addition, it appears that the areas precut to depths of 1 inch or 1 ½ inch produced fewer natural transverse thermal cracks. By 2014, the 0.5 inch precut depth produced the highest number of natural transverse cracks in all precut subsections. The data suggests that there is some degree advantage to deeper precuts although there is no evidence that a 1 ½ inch cut depth is better than a 1 inch cut.

In addition, pavement cores were obtained from the experimental subsections on September 10, 2014. The binder content determination test was conducted in accordance with AASHTO T 308 ignition method. It can be seen that the field core test values are very close to the quality control data. Numerical analysis of a pavement structure realistically modeled on the Richardson Highway research area pavement structure was performed. The results were consistent with preliminary findings from the field observations which showed that increasing the cutting depth performed better in terms of controlling random occurrence of crack, and 25' spacing was more effective than 40' spacing with less amount of cracks occurred.

In a summary, precutting technology has been shown to work well in cases where roadway construction has included placement of at least several feet of new material. This has been demonstrated in Minnesota as well as by the 30-year-old test section at Fairbanks, Alaska. With the caveat that the Richardson Highway experimental section reported herein has been monitored for only two years, this research tentatively indicates that precutting can significantly benefit the thermal crack performance of a pavement resurfacing project.

Findings presented in this report were based on preliminary results from a relatively short time period. Continuing to survey and monitor these four subsections is recommended. Careful measurements of width variations of the precut slots throughout at least one annual temperature cycling would be required to define which precuts have become active. It would be helpful to compare/correlate future findings from precutting subsections with field practice of crack sealing and recommend an effective design methodology and construction practice to control thermal cracking in AC pavements for Alaska and cold areas of other northern states.

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I. INTRODUCTION

PROBLEM STATEMENT

The Alaska Department of Transportation & Public Facilities (AKDOT&PF) wants to construct and maintain asphalt concrete (AC) paved highways in a way that minimizes roadway lifecycle costs while preserving acceptable performance. Many states are faced with the challenges of aging, degrading roadway pavements, and low temperature cracking is one of the most prevalent pavement distresses found in Alaska and cold areas of other northern states. Thermal cracking is a natural feature of most paved Alaska roadways that influences both long term maintenance costs and the driving public's perception of road performance. This requires significant repair efforts to maintain an acceptable pavement condition. The low temperature cracks are extensive enough that a significant portion of DOT Maintenance and Operations budget is allocated to sealing and associated work required to repair them. Until new technologies may someday eliminate cracking, considerable funds will continue to be spent on crack sealing and associated work. Innovative and cost effective approaches and techniques to preserve and maintain existing highway systems are needed. Precutting of thermal cracks in asphalt concrete pavements has provided promising results in controlling pavement degradation usually associated with natural thermal cracking, according to the field observations in Alaska (since 1984) and Minnesota (since 1969). However, a systematic approach has not been developed to implement optimum application of this technique in AC pavements, especially when the thermal cracking actually involves both the AC layer as well as the underlying aggregate.

By definition major transverse thermal cracks span the entire pavement width. After post-construction exposure to even a single winter of Alaska's low temperatures, major transverse thermal cracks begin to appear on nearly any road constructed in central or interior areas of Alaska. With the passing of additional winters it is normal that transverse cracking continues to develop at a decreased spacing, and individual cracks often become wider. Major transverse thermal cracks penetrate completely through the AC pavement and extend downward, sometimes several feet, into underlying aggregate materials. Such cracking produces the rhythmic bumps that are familiar to most Alaska drivers. Because major transverse cracks are the most noticeable type of thermal cracking, they have traditionally received the lion's share of maintenance sealing effort.

It is important to emphasize that the most critically important single distinguishing characteristic of major transverse thermal cracking is that it extends across the full width of the paved surface. Two examples of major transverse thermal cracks are shown in Figure 1. Figure 1 compares a 1984 precut Phillips Field Road crack with a natural major transverse thermal crack on another local Fairbanks, Alaska road. Both pavements were about 30 years old at the time of this report. Neither crack had ever been sealed. The precut crack provides a much better appearance. The natural crack looks much worse, exhibiting both spalling and bifurcation.

Figure 1. 25+ year old major transverse thermal cracks, precut (lt.) natural (rt.)

The authors strongly argue that the better appearance of precut transverse cracks, especially in urban areas, provides the impression that the pavement has been more "professionally finished." On the other hand, although offering a somewhat broken appearance, general pavement performance in the vicinity of the natural crack (right hand photo in Figure 1) remains generally acceptable after 30 years. In fact, very recent Alaska research (McHattie, Mullin, and Liu, 2013) found considerable evidence that even the most ragged-appearing natural thermal cracking has most often posed little problem with respect to general pavement performance. But appearance and perception of quality construction is important. Regardless of other benefits, the driving public as well as most highway agency engineers would tend to perceive a successfully precut pavement as being less in need of maintenance than its naturally cracked counterpart.

BACKGROUND

Road-width thermal cracks (major transverse cracks) are perhaps the most noticeable form of crack-related damage on AC pavements throughout colder areas of Alaska. In these cold areas it has as yet not been possible to prevent this crack type from forming. To date, this appears to remain true regardless of paving material, embankment material, or construction method. Development of major transverse cracking is an inescapable fact throughout Alaska. However, based on previous field tests in Alaska, it appears possible to greatly improve road surface appearance, potentially reduce ride roughness, and justifiably minimize much of the maintenance effort associated specifically with this crack type.

In 1984 a research project began to figure out the problem of transverse thermal cracks in a practical way. The basic idea behind this project was that if the thermal cracks could not be prevented, it would be possible to create an acceptable form of transverse thermal cracking. An Experimental Feature research project was started at the time to investigate the possibility that “better” thermal cracks could result if the location and form of the crack could be controlled by precutting a thermal crack pattern in a new pavement. The technique, applied on Phillips Field Road in Fairbanks, AK in October of 1984, consisted of cutting thin slots through the pavement to within about ¼ inch of the bottom of the new asphalt concrete layer. The thin saw cuts were made perpendicular to the road’s centerline from edge to edge on the pavement surface. Spacing between presawn thermal cracks was 50 feet. The 50-foot precutting interval was chosen because it was the average of many measurements of natural thermal crack spacing from research work previously done in interior Alaska. Unbeknown to Alaska researchers at the time the test section was proposed, the Minnesota DOT had experienced success with presawn thermal cracks since first testing the technique in 1969 (Morchinek 1974). After about 30 years, the Philips Field Road precut section remains in very good condition. The precutting done on the heavily trafficked Phillips Field Road has been an unqualified success. Some of the presawn cracks became active thermal cracks (as evidenced by significant subsequent movement) and some did not. Of the presawn cracks that did not become active thermal cracks, the precutting did no long-term harm to the pavement; the precut lines are visible, but there has been essentially no degradation of the pavement adjacent to the precut lines.

During the 2012 construction season, transverse crack precutting was done within a 1-mile section of AKDOT&PF’s Richardson Highway Mile 340 to 346 project (about 16½ miles southeast of Fairbanks, AK). The Richardson Highway precutting test area includes a ¼ mile control section with no precutting.

OBJECTIVES

The main objective of this report is to recommend design strategies and construction practices aimed at controlling thermal cracking—and thermal cracking maintenance economics—in AC pavements for Alaska and cold areas of other northern states.

The intermediate objectives of literature review, crack surveys, laboratory testing, and numerical modeling supported the main objective indicated above:

- Literature Review attempted to locate information specifically pertaining to benefits or disadvantages regarding the precutting techniques used for AC pavements and apply it to the present research.
- Crack Surveys required comparing various precut strategies (variations of cut spacing and depth), with the locations of natural major transverse cracks both before and after construction. This addressed the question of whether post-construction major transverse cracks were occurring as reflection cracks, i.e., at the preconstruction crack locations or being “trained” to occur at the precut locations.
- Laboratory Testing provided basic data about the physical properties of the AC and confirmed that the properties remained reasonably consistent from test subsection to test subsection.
- Numerical Modeling provided insights into the mechanics of low temperature cracking in a multi-layered (AC + aggregate layers) pavement structural systems.

Research Approach

The objectives of this research study were met using the approach outlined in this section. As explained below, each element of the research approach is addressed in one or more chapters of this report:

- Literature review
- Experimental modifications of pavement in a selected construction project
- Data collection
- Presentation of data and analyses
- Discussion and integration of analyzed data
- Present conclusions and provide implementation guidelines

Literature Review The literature review contained in Chapter II, summarizes selected items of the engineering literature directly relevant to precutting of pavement-type structures and control of thermal cracking in general.

Experimental modifications of asphalt concrete pavement in a selected construction project This is covered in Chapter III. Approximately a 1-mile section of an AKDOT&PF resurfacing construction project (constructed in 2012) was chosen as a field area for the research project. The construction project was identified in contract documents as: IM-0A2-4(31)/63362, Richardson Highway MP 340–346 Resurfacing (Moose Creek), Paving and Bridge Rail Retrofit, and is located about 16½ miles southeast of Fairbanks, Alaska. The section of the project designated for research extended just over one mile, from project Station 989+95 to Station 1043+44. Stationing extended north to south. This section was situated roughly between Mile Posts 343 and 344 (these are physical milepost markers located at the roadside). The southernmost subsection was located approximately at the Eielson Farm Road intersection. AKDOT&PF's Pavement Management System data indicated an AADT of about 4,000 (2011 data), for the preconstruction wearing course placed in 1998.

The mile long experimental section was subdivided into four subsections of ¼ mile each. A quarter mile control section was located on the north end (no precutting). The next two quarter mile sections were precut at 25 feet and 40 foot intervals respectively. The last (southernmost) quarter mile subsection received precuts at the locations of the preconstruction natural cracks.

Three cut depths were employed within subsections 2 and 3 where precutting was done. One third of the cuts were 0.5" deep (north end of subsection), a third of the cuts were 1" deep (middle), and a third of the cuts were 1.5 "deep (south end).

Data Collection Data collection is discussed in Chapters IV and V. Field data consisted of photos (obtained in 2012, 2013, and 2014), crack location surveys (done in October 2013 and March 2014), and laboratory results from pavement core samples obtained in September of 2014. Appendix A contains examples of blank and completed field data sheets used for the crack surveys. Data obtained from the AKDOT&PF included construction plans, construction plan as-builts, materials test data, ground penetrating radar data, pavement management data, and documentation explaining the construction process regarding the research area. Laboratory test data for the AC pavement cores collected in 2014 was provided.

Presentation of Data and Analyses Materials data from the laboratory and construction project records are presented in Chapter IV. These data are included to document the kind of materials used within the experimental section, and moreover, to show the degree of variation in the materials from subsection to subsection—basically as a way to demonstrate that the four subsections were constructed similarly prior to precutting.

Raw data obtained from the crack surveys are presented in tabular form in Appendix B. Analyses and discussion of the crack survey data are presented in Chapter V. Crack survey data is the "heart" of the research project. Analysis of these data compares the locations of preconstruction natural major transverse thermal cracks with the post-construction crack frequency and locations.

Chapter VI is devoted to the numerical analysis of a pavement structure realistically modeled on the Richardson Highway research area pavement structure. This was done for two reasons: 1) as an attempt to define geometry, input parameters etc. appropriate to provide a realistic modelling of the actual multilayered pavement/sub-pavement structure and interior Alaska temperature inputs, and 2) in order to help explain some of the observed characteristics associated with natural thermal cracking.

Discussion and Integration of Analyzed Data This is covered in part in Chapters IV through VI, and more completely in Chapter VII as part of the process of forming conclusions. This process considered pertinent information obtained from crack surveys, materials data, numerical modeling, and the literature review. It is this process of digesting and integrating research findings which leads to useful conclusions that satisfy the research objectives.

Present conclusions and provide implementation guidelines This is covered in Chapter VII. This activity condenses useful and economically practical results of the research effort down to a useful form. The chapter presents conclusions that support an implementation strategy. It then provides specific implementation guidelines according to that strategy.

II. LITERATURE REVIEW

The literature review begins with an introduction and summary that provides general background into the subject area of thermal cracking. These sections cover some of the engineering "science" of thermal cracks (causes, characteristics, etc.) and maintenance of thermal cracking in road pavements.

Following the two sections of general overview, two Minnesota DOT reports are presented that document research directly pertinent to the subject of this report, i.e., precutting of roadway pavements as a way of controlling the frequency and severity of thermal cracking. The main effort of this research was directed toward field experimentation, and an exhaustive literature review was not an intended part of the work. However, enough of a literature search was done to realize that additional relevant documents (documents not directly derivative of the cited Minnesota reports) may be very difficult to locate.

INTRODUCTION TO THERMAL CRACKING (McHattie et al. 2013)

There are many different types of cracking in flexible pavements; fatigue, transverse, block, longitudinal, edge, construction joint, reflective, and slippage cracking (Huang 2004). Although there are some common causes for the various cracks there are also unique reasons for each type of crack. Transverse thermal cracking is an opening in the asphalt perpendicular to the travel of traffic. Thermal cracks occur when the constrained thermal contraction stress exceeds the tensile strength of the asphalt although some theorize openings in the base and or subgrade layers could be the cause (Dore and Zubeck 2009). The effect of this can be seen in cold areas with cracks that extend beyond just the pavement and into adjacent bike paths, sidewalks, and in between vegetated areas (Osterkamp 1986). These cracks often start with spacing around 40 ft. As the pavement ages and hardens the spacing becomes closer. When spacing is close to the width of the road longitudinal crack will occur and interconnect with the existing transverse cracks. In Alaska thermal cracks are sometimes referred to as major thermal cracks and minor or map thermal cracks (McHattie et al. 1980). Dore and Zubeck (2009) further defined thermal cracking into low temperature thermal cracking and thermal fatigue cracking. They defined low temperature cracking that occurs when there is a rapid temperature drop. Thermal fatigue cracking occurs where there is diurnal temperature cycling but the absolute temperature never reaches the temperatures mentioned for low temperature thermal cracking.

Thermal cracking has been defined in some literature sources as a pavement surface distress type that occurs in cold regions and which displays itself as an opening perpendicular to the flow of traffic. It starts with spacing 30 meters to 40 meters and as the pavement age-hardens the spacing becomes less. When the spacing approaches the width of the road then thermal cracking will interconnect with longitudinal lesser cracks. This is different than longitudinal cracks from other issues such as differential heaving.

Although most describe thermal cracking as occurring in the wear layer some have observed thermal cracks in more extreme cold regions such as the interior of Alaska to go beyond the edge of the pavement and across medians, across non-paved shoulders to bike paths and even across frontage roads. Two types of thermal cracks have been described, one being major transverse thermal cracks and the other as a lesser form of map, block or grid cracking.

These cracks have also been described as low temperature cracking that occurs in the more extreme low temperature areas where a rapid cooling cause a crack as opposed to a diurnal daily temperature cycling that acts as a thermal fatigue stress failure.

The factors influencing thermal cracks are temperature, rate of temperature change, coefficient of thermal contraction, pavement slab geometry, constraint, aging, stiffness, fracture toughness, fracture energy, polymer additives, RAP content, air voids, and sometimes mixture aggregate.

Testing related to thermal cracking is either for binders or mixtures. Binder tests are the BBR, DTT, and DENT. Tests related to mixtures are the IDT, TSRST, Modified IDT, DCT, SCB, SENB, and the dilatometric test. A new test, i.e., the Asphalt Binder Cracking Test (ABCD) (Kim 2007) has been gaining acceptance as a way of evaluating asphalt binders in the laboratory.

There are two types of thermal crack modeling, one is empirical and the other is mechanistic. The empirical has been pronounced effective for the range of data used to create the predictive equations. Mechanics based methods are considered more generally applicable (provided correct input values are used). The latest approach to account for thermal cracking in pavement design is a modified TCMODEL approach. It consists of a three-step process and incorporates a graphic user interface to assist input. Thermal stress applies the load, parameters determined in a fracture-energy based test supplies some of the material properties. Thermal crack spacing is predicted.

Treatments for cracks are either sealing or filling depending whether cracks are working or non-working. These terms are defined by the amount of horizontal movement an opening will undergo annually. All thermal cracks are considered to be working cracks therefore sealing is recommended.

Many agencies seal cracks because of past practices and policies. Some agencies seal cracks based on a rating such as a PDI. There are localized areas or situations where cracks are not sealed at all. Some of the literature suggested that a more holistic approach be applied and that statistically meaningful experiments should be designed to determine the cost effectiveness of treating cracks. Even in areas where sealing is a common practice, control sections with no sealing should be used as a baseline from which to measure crack treatment performance. Wisconsin DOT does not seal cracks in PCC sections stating it is saving $6,000,000 annually. If it is determined that crack sealing is cost effective then use a material and method that provides the best life cycle costing.

There are three types of sealants: cold applied thermoplastic bituminous materials, hot applied thermoplastic bituminous materials, and chemically cured thermosetting materials. The criteria for choosing sealant materials should consider; short preparation time, quick and easy to place, short cure time, adhesiveness, cohesiveness, resistance to softening and flow, flexibility, elasticity, resistance to aging and weathering, and abrasion resistance.

The FHWA (1999) manual for crack treatments detailed a stepwise procedure for crack treatments, applicable specifications, and performance criteria. No treatment will be successful if installation is inadequate.

There have been several studies related to thermal cracking in Alaska by McHattie et al. (1980), Osterkamp et al. (1986), Raad et al. (1995), and Zubeck et al. (1999). Hicks et al. (2012) presented guidelines for pavement preservation in Alaska, in which a survey of Northern countries such as Canadian Provinces, Norway, Finland, China, Japan and some US states bordering Canada showed crack sealing is presently the most used pavement preservation treatment.

TECHNOLOGY REGARDING PRECUTTING OF TRANSVERSE CRACKS

Transverse cracks develop in all asphalt concrete paved roads. It is known that as temperature varies, materials expand and contract. When the upper portion of the asphalt concrete pavement structure contracts, due to lower temperatures, stress in that structure overcomes its ability to withstand cracking. Asphalt pavement also becomes brittle at lower temperatures, lowering its elasticity and increasing its rigidity.

Some studies have tried to resolve the issue of transverse thermal cracks in asphalt pavements by designs that add precut cracks during construction. Although there would still be cracks in the road, the manmade cracks would at least be straight and therefore more aesthetically pleasing than the result of natural thermal cracking. As to the economic benefit of precutting, it was thought that such a design feature would produce a smoother ride, and potentially lower the roadway's lifecycle cost.

The expectation has been that precut cracks could reduce post-construction maintenance costs considerably by reducing the need to seal cracks or seal, fill, or patch spalled areas of cracking later in the pavement's life. Crack sealing is the most commonly performed preventative maintenance activity on asphalt pavements.

This review looks at two studies on thermal crack mitigation. The first study is titled "Sawing Joints to Control Cracking in Flexible Pavements" (Morchinek 1974). This Minnesota Department of Transportation study was a seminal experiment where a few AC road sections were precut, and the cracks were evaluated for the next five years. The second study titled "Sawing and Sealing Joints in Bituminous Pavements to Control Cracking" (Janisch 1996) is a Minnesota follow-up to the 1974 research report, and more extensive experiment than the first project.

Sawing Joints to Control Cracking in Flexible Pavements (Morchinek 1974)

One of the first experiments of its kind, Special Study No. 315 of the Minnesota Department of Highways (MDOT) was constructed in the late 60s and evaluated annually over five years. There were five sections in this experiment. In each of three of the sections, a different precut spacing was evaluated. Evaluated were 40, 60, and 100 foot spacing. Two control sections were designated; these received no precuts. Two different types of precutting methods were investigated, i.e., liquid sealed joints at ¼ inch width and neoprene sealed joints at 7/16 inch width. All pre-cut cracks in this experiment were cut to a depth of 3 inches. The experiments were built into I-35, which at the time had an average daily traffic level of 8,700. The report clearly stated that researchers wanted to discover if the locations of natural transverse thermal crack could be generally controlled. It was hoped that most or all of the precut slots would eventually become locations of active, natural thermal cracks. Given that this was an initial research effort along this line, there was no attempt at optimization regarding variables such as crack sealant materials, sealant installation methods, precut spacing or saw-cut dimensions.

The typical section of pavement structural layering involved in this experiment was fairly robust. Layering consisted of the following top-down sequence: 1.5 inches asphalt concrete wearing course, a 2 inches asphalt concrete binder course, 4.5 inches bituminous base, 4 inches bituminous treated base, and 12 inches granular material. It was recognized that more studies of a similar nature would be needed to gather enough data to apply this knowledge to other locations and typical sections.

The collected data was plotted in “crack maps” that graphically displayed thermal cracking development in the experimental and control sections for each of the five years. It was very apparent that uncontrolled cracking developed in the two control sections while very few uncontrolled cracks formed in the three test sections. The section with 100 foot spacing showed a few cracks after five years while sections with 60 and 40 foot precut spacing presented almost none. This experiment seems to have provided a definite yes regarding the question of whether precutting can, given the right conditions, control the location of transverse thermal cracks.

The researchers noted that the neoprene sealant was apparently not properly installed and therefore quickly deteriorated. It appeared that the sealant was not fully adhering to the sides of the cracks. This issue did not adversely affect the research as the researchers were mainly looking at the prospect of influencing thermal crack locations and not sealant performance per se.

A concern about this experiment is the short period of data collection. Typically, roads are built with a design life of between 15 and 25 years. The report objectively studied only the first five years of performance, and drew conclusions based only on that period. In the report section where the authors considered the economic feasibility of precutting, they assumed a 17-year pavement life and further assumed that they would never have to seal transverse cracks during that time. Economic feasibility appeared to require a precut spacing of 60 feet while the report showed that a spacing of 40 feet or less would be the most effective for controlling thermal cracking. The cost effectiveness determined in the early 1970s, and based solely on this experiment, is tenuous. The report shows that precutting could be cost effective pavement design feature given the assumptions made.

It should be noted that no harm was done to the road as a result of the MDOT precut experiment. The lack of negative pavement performance signs due to the precutting was itself an important finding.

This experiment was a significant first step toward effectively controlling the location and final form of transverse thermal cracks using a simple construction technique. The experiment indicates that precutting can be a cost-effective addition to pavement construction that proactively handles the inevitable issue of transverse thermal cracking and related road performance issues. This experiment demonstrated that precutting worked, a fact that fairly demanded continued investigation along this line. The experiment's results spurred additional research efforts including additional field experiments; a new and more extensive project was conducted by MDOT in the 1990s.

Sawing and Sealing Joints in Bituminous Pavements to Control Cracking (Janisch 1996)

This project, documented in Report number 96-27 (March 1996), is much more extensive than Special Study No. 315. MDOT evaluated over 50 test sections where they performed what they called the "saw and seal" technique to prevent natural uncontrolled thermal transverse cracking in pavements. "Saw and Seal" is a name that MDOT coined to describe the process of precutting cracks into asphalt concrete and sealing with a standard road sealant. Several kinds of typical sections were evaluated including: new asphalt concrete on granular base (NEW), overlays of bituminous pavement over Portland cement concrete pavement (BOC), and overlays of bituminous pavement over bituminous pavement (BOB) pavement.

It was necessary for MDOT to develop a simple metric that could be used to score the degree of success of individual saw and seal projects. They developed a simple equation which divided the number of precut cracks by the number of precuts plus new cracks:

$$C\text{[illegible]}\ \&\ Seal\ S\text{[illegible]}ce\text{[illegible]} = \left[\frac{N\text{[illegible]}o\text{[illegible]}P\text{[illegible]}C\text{[illegible]}}{(N\text{[illegible]}o\text{[illegible]}P\text{[illegible]}C\text{[illegible]}+N\text{[illegible]}C\text{[illegible]}}\right] \times 100$$

If that number was greater than or equal to 85 percent then the section was successful. Of the over 50 sections studied, more than 75 percent were successful, over 5 years, using saw and seal and the metric described above.

Based on observation of approximately 50 test sections, this study identified some types of pavement structures that are more benefited by the saw and seal technique and others. New pavements had the highest success rate at about 85 percent of all projects, BOC at 82 percent and BOB at only 37 percent. The BOC failures were reported as mainly unsuccessful when there was preexisting “mid-block” cracking. Lastly the BOB sections did not align the new (precut) cracks over the old cracks, and almost all of the older cracks reflected through the pavement. In one section where the existing cracks were fairly straight, the construction crew put the new precut cracks over the old ones which gave a 100 percent success rate, i.e., no new crack formed in this section.

All precuts were treated using a special sealant installation technique. The experimental sections used a reservoir system for sealing each precut crack. Along the top of each 3mm wide precut, a large square slot was milled, about 5/8 inches wide x 5/8 inches deep. The milled slot extended the full length of the precut crack. Beneath each milled slot, the 3mm wide precut extended to a depth of 64mm, i.e., to 1/3 the total thickness of the pavement. The reservoir system was intended to hold the crack sealants effectively in place during the expansion/contraction cycles expected to occur if and when the cracks became “active.” An active crack is created when natural thermal cracking occurs at the precut location. Once becoming active, the precut crack will cycle in width according to temperature variations within the pavement structure. The additional sealant width provided by the reservoir system means that the sealant will strain less for a given amount of crack width expansion.

The MDOT experiment looked at precutting in the environmental setting of Minnesota and considering the materials used in that area. Different sealants and saw-cutting techniques may need to be evaluated for different areas. The sealant specifications in the report required an effective in bond strength down to -20 degrees Fahrenheit and flexibility to -30 degrees Fahrenheit. It goes with little further comment to state that specific methods and materials used by MDOT may not be directly applicable in places such as Alaska.

Besides ruling out some pavements for the saw and seal technique, the study uncovered many problems that could arise. Some of the issues examined in the study were sealant-to-pavement adhesion failures, certain crack sealant type failures, questions of precut dimensions, and questions regarding construction/constructability.

The report did not contain the locations or pavement ratings of each section. It also did not present the data as it was illustrated by very clear graphics in Special Study No. 315. The writers stated that a follow-up report could address these shortcomings.

III. DESCRIPTION OF RESEARCH AREA

CONSTRUCTION PROJECT / RESEARCH AREA LOCATION

Experimental saw cutting (precutting) was done as part of the Richardson Highway MP 340 to 346 resurfacing (Moose Creek)/63362 project. A mile-long experimental section was defined on the project as starting about 16 ½ miles highway miles southeast of Fairbanks of the Richardson Highway and extending about 1 mile southeast along the highway in the southbound lane. Figure 2 shows portion of a Google Earth computer screenshot that indicates the location of the Richardson Highway research sections with respect to the State of Alaska boundaries. Figure 3 shows the general location of the research area with respect to the nearby city of Fairbanks, Alaska. Figure 4 shows the general location of the test section with respect to the Eielson Farm Road/Richardson Highway intersection.

Figure 2. Location of research site within Alaska (from Google Earth)

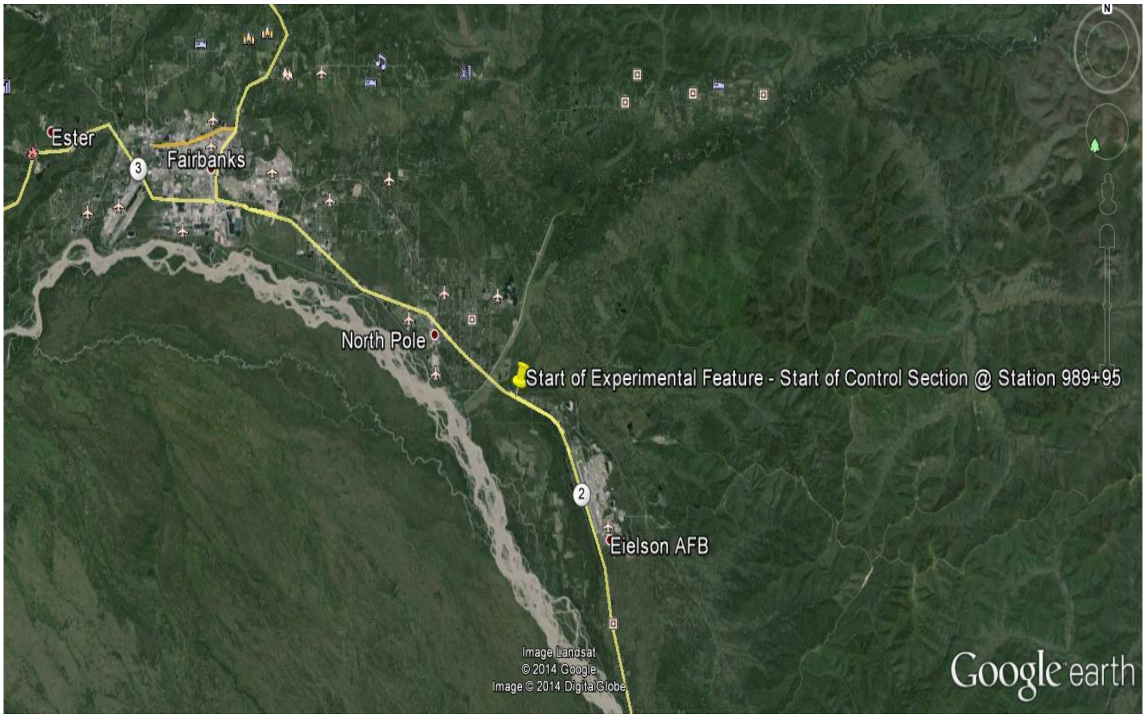


Figure 3. Location of research area with respect to Fairbanks, AK (from Google Earth)

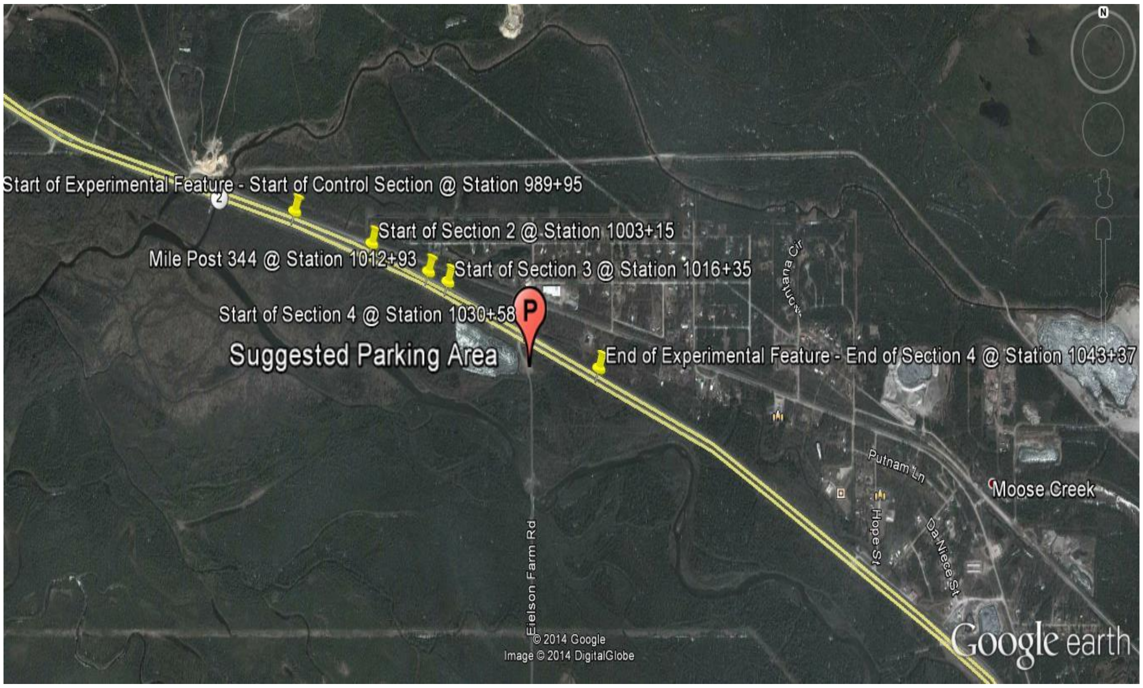


Figure 4. Larger scale view of research area on Richardson Hwy. (from Google Earth)

Latitude/longitude coordinates (according to Google Earth and WGS 84 base) are provided to aid locating the precut research section on the Richardson Highway at a future time when research-related pavement markings have disappeared:

Start of Subsection 1 (Station 989+95) is 64°43’08” N Lat., 147°13’01” W Long.
End of Subsection 4 is 64°42’49” N Lat., 147°11’06” W Long.

The entire research area is located on a nearly straight section of the Richardson Highway that has very little topographic variation and is at an elevation of about 500 above sea level.

RESEARCH LAYOUT / PRECUT DESIGN/EXECUTION

The experimental cuts were made at various spacing (25’, 40’, and special spacing) and to 3 different depths (0.5”, 1.0”, and 1.5”). Precut work was performed by an employee of Great Northwest, Inc., the construction project’s main contractor, on the southbound lanes. During cutting, traffic control consisted of closing a single lane of the two south bound lanes. The single lane closure allowed cutting of approximately two thirds of the 2-lane width from one side of the road. After all cuts were partially completed, the lane closure was switched to the adjoining lane to allow completion of the saw cuts. The cuts extended from edge of pavement to edge of pavement (full 2-lane width) at each cut location. Saw cutting of the 111 full-width slots required three full workdays. Weather during the sawing operation ranged from partly cloudy to rain, with temperatures between 50 and 80 degrees F.

The equipment used was a Saw Devil walk-behind saw machine with a 12” diamond saw blade (one eighth inch thick) and a flatbed truck with a 300 gallon tank of water for cooling the saw blade. The time required to layout and cut the first two thirds of each line was approximately 12 minutes, or about 15 minutes total per line plus time required to move the cutting operation from one lane to the other. This time was averaged over several of the different depths of cuts. Figure 5 shows the saw equipment as well as the type of thin diamond saw used.

Figure 5. Saw Devil equipment and operator (lt) and thin diamond saw blade used (rt)

The experiment was composed of four subsections, including the critical control section. No saw cutting was done within the control section. Saw cutting was done in the southern three subsections, i.e., between Stations 1003+15 and Sta.1043+38. For subsections receiving precuts, the cuts were made to various depths and spacing indicated in the following list:

- Section 1: Sta. 989+95 to 1003+15. This section is the Control Section without saw cuts.
- Section 2: Sta. 1003+15 to Sta. 1016+35. This section has 17 cuts of each of the three depths (0.5", 1.0", and 1.5") each 25' apart.
- Section 3: Sta. 1016+35 to 1029+55. This section has 11 cuts of each of the three depths (0.5, 1.0, and 1.5) each 40' apart.
- Section 4: Sta. 1030+30 to 1043+38. This section has a different number of cuts for each depth (7 at 0.5", 10 at 1.0" and 11 at 1.5") and the cuts are located over the cracks in the asphalt that was replaced (the preconstruction natural thermal cracks).

IV. MATERIALS PROPERTIES

Samples from test sections were cored from the field site and tested at the Civil Engineering Laboratory at the University of Alaska Fairbanks. These were cored at random locations within each of the four subsections. The 6” diameter cores were centered on the saw-cut lines except in the control subsection where no precutting was done. Figure 6 shows the coring operation and the location of the core barrel as it is centered on a saw cut line prior to drilling.

The asphalt concrete pavement was underlain by a crushed base course consisting of material reclaimed from previously existing pavement. The pavement and reclaimed base were underlain by existing aggregate layers that remained in-place and undisturbed since the previous construction.

Ground penetrating radar (GPR) data obtained in 2010 by the AKDOT&PF Northern Region Materials Section were provided to the research project. These data contained GPR-based estimates of pavement and base course thicknesses for the entire mile-long experimental section prior to construction. These data indicated an average asphalt concrete pavement thickness of 1.3 inches (sample standard deviation = 0.2 inches) and an average base course thickness or 5.4 inches (sample standard deviation = 0.9 inches). These materials, reconditioned and lying beneath the present asphalt pavement, were not sampled and tested as part of this research project. Assumptions were made regarding this material that were considered reasonable by the research team. Based on a history of generally acceptable pavement performance prior to resurfacing, the aggregate materials below the asphalt concrete pavement were assumed to be well graded gravels, i.e., compactable, gravels with a fines content of probably 6 percent or less (non-frost-susceptible material). These base and sub-base materials were assumed to have no special properties with respect to thermal expansion/contraction that should set them apart from other gravel materials found throughout Alaska.

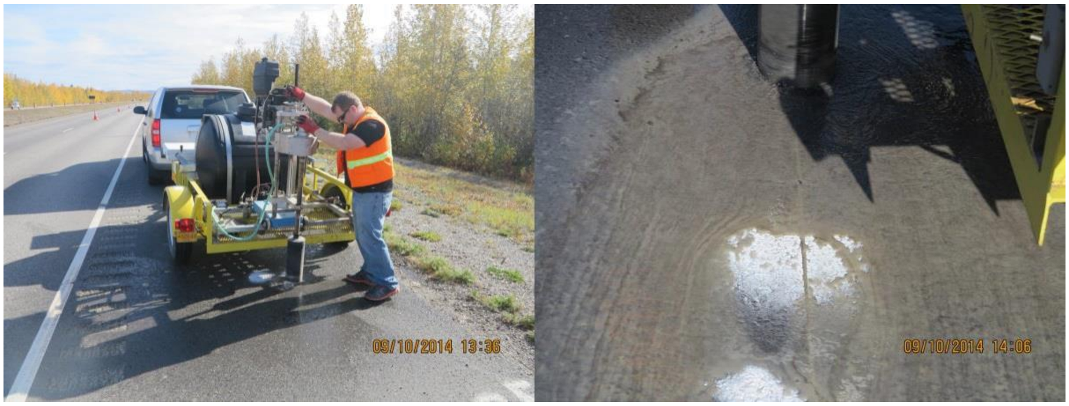


Figure 6. Richardson Hwy. core sampling operation September 10, 2014

ASPHALT CONCRETE SPECIFICATIONS & MARSHALL MIX DESIGN

AC mixtures used on the project was designed and placed according to AKDOT&PF Standard Highway Construction Specification Section 401, Asphalt Concrete Pavement. The specific mix requirement was according to 401(2), Asphalt Concrete, Type II; Class B. Performance-graded asphalt cement — PG 52-28 — was the binder used in the AC mix throughout the resurfacing project. The project's PG 52-28 asphalt cement was equivalent to AC 5 asphalt cement materials commonly used over the past 30 to 40 years in Alaska, and did not incorporate modifier additives. The required mix design had to meet the requirements of AKDOT&PF specification 401-2.01 and the requirements indicated in Table 1 below using the job mix design procedure detailed in ATM 417 (an AKDOT&PF test method). A 2-inch compacted pavement thickness was placed throughout the experimental section.

The AC aggregate gradation specification is included in the following section. Crushed aggregate used in the AC mix was required to meet the requirements of Highway Standard Specification 703-2.04 as indicated in Table 2 (see yellow-highlighted column).

Table 1. AC Marshall mix design requirements per AKDOT&PF specifications (Table 401-1)

ASPHALT CONCRETE MIX DESIGN REQUIREMENTS DESIGN PARAMETERS	CLASS "A"	CLASS "B"	CLASS "C"
Stability, pounds	1800 min.	1200 min.	750 min.
Flow, 0.01 inch	8-14	8-16	8-18
Voids in Total Mix, %	3-5	3-5	2-5
Compaction, number of blows each side of test specimen	75	50	35
Percent Voids Filled with Asphalt (VFA)	65-75	65-78	70-80
Dust-asphalt ratio*	0.6-1.4	0.6-1.4	N/A
Voids in the Mineral Aggregate (VMA), %, min.			
Type I	12.0	11.0	N/A
Type II	13.0	12.0	N/A
Type III	14.0	13.0	N/A

Table 2. AC aggregate per AKDOT&PF specifications (Table 703-3)

BROAD BAND GRADATIONS FOR ASPHALT CONCRETE PAVEMENT AGGREGATE

SIEVE GRADATION

Percent Passing by Weight

	Type I	Type II	Type III
1 in.	100		
3/4 in.	80-90	100	
1/2 in.	60-84	75-90	100
3/8 in.	48-78	60-84	80-90
No. 4	28-63	33-70	44-81
No. 8	14-55	19-56	26-70
No. 16	9-44	10-44	16-59
No. 30	6-34	7-34	9-49
No. 50	5-24	5-24	6-36
No. 100	4-16	4-16	4-22
No. 200	3-7	3-7	3-7

DATA FROM AKDOT&PF CONSTRUCTION ACCEPTANCE TESTS

AKDOT&PF Marshall target mix design parameters are shown in Table 3. Acceptance samples are used for quality assurance in order to approve payment to the contractor. Table 4 contains acceptance sample test data obtained from AKDOT&PF sources. All test data available from the general vicinity of the experimental section is included in Table 4. These include data for locations at two (2) project stations just north of the experimental subsections, five (5) station locations within three of the experimental subsections, and two (2) station locations south of the experimental subsections. These data are included to provide an indication of the uniformity of the asphalt concrete material used within and somewhat beyond the limits of the experimental subsections. Table 5 provides descriptive statistics for the Table 4 data.

Table 3. AKDOTF project mix design target values

% Asphalt Cement	Compaction % of Max. Theoretical Density	% Pass ¾”	% Pass ½”	% Pass 3/8”	% Pass #4	% Pass #8	% Pass #16	% Pass #30	% Pass #50	% Pass #100	% Pass #200
5.0	94	100	83	72	49	36	29	25	18	8	5.0

Table 4. Project quality control test values

Location Of Sample	% Asphalt Cement	Compact. %	% Pass ¾”	% Pass ½”	% Pass 3/8”	% Pass #4	% Pass #8	% Pass #16	% Pass #30	% Pass #50	% Pass #100	% Pass #200
949+00 [1]	4.7	97	100	82	71	47	34	28	24	18	9	5.7
980+00 [1]	5.1	97	100	84	74	51	38	30	26	19	10	6.6
992+05 [2]	5.0	98	100	90	77	50	37	29	25	18	9	5.8
1016+00 [3]	5.0	98	100	84	73	49	36	30	26	19	10	6.3
1031+50 [4]	5.4	95	100	87	81	53	39	32	28	20	10	6.8
1031+75 [4]	4.8	96	100	79	67	47	35	28	24	17	9	5.7
1032+50 [4]	5.0	95	100	87	76	53	38	31	27	20	10	6.5
1058+50 [5]	5.0	94	100	84	69	47	35	29	26	19	10	6.3
1083+00 [5]	5.2	96	100	89	75	51	37	30	26	19	10	6.6

1: north of control section 2: within control section 3: border of control section & section #2

4: within section #4 5: south of section #4

Table 5. Averages and standard deviations for quality control test values

	% Asphalt	Compact %	¾”	½”	3/8”	#4	#8	#16	#30	#50	#100	#200
Average	5.0	96	100	85	74	50	37	30	26	19	10	6.3
Standard Deviation	0.2	1.4	0	3.5	4.3	2.4	1.7	1.3	1.3	1.0	0.5	0.4

Pavement cores were obtained from the experimental subsections on September 10, 2014 as part of the reported research work. Data from analyses of these core samples are contained in Tables 6 and 7. It is compared to the above project data to verify uniformity of the paving materials throughout the experimental subsections.

DESCRIPTION OF PAVEMENT CORES & LABORATORY RESULTS

A total of 12 field cores, three for each section, were collected from the four sections. Typical representatives of field cores from each section are shown in Figure 7.

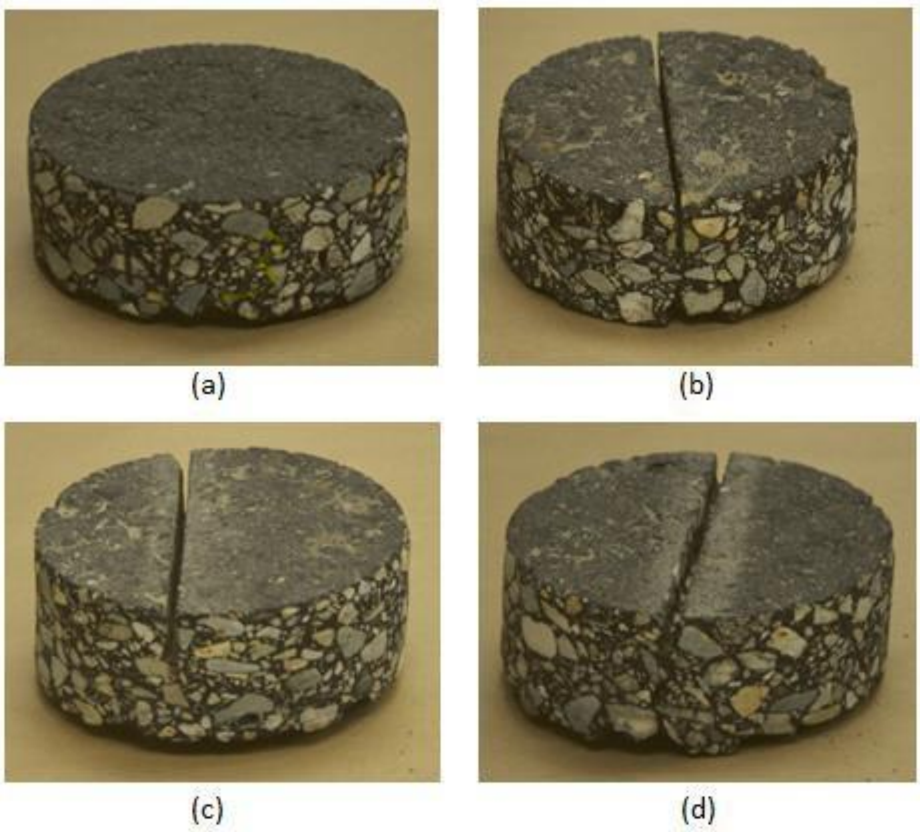


Figure 7. Field cores from all the four sections: (a) section 1; (b) section 2; (c) section 3; (d) section 4

The binder content determination test was conducted in accordance with AASHTO T 308 ignition method. Based on the quality control data, the nominal maximum aggregate size was ¾ in (19mm), thus 2,000 g was selected as the mass of each sample. The sieve analysis was conducted subsequently. Tables 6 and 7 show the results and descriptive statistics, respectively. It can be seen that the field core test values are very close to the quality control data.

Table 6. Field cores test values

Section ID	Field Core ID	% Asphalt Cement	% Pass ¾”	% Pass ½”	% Pass 3/8”	% Pass #4	% Pass #8	% Pass #16	% Pass #30	% Pass #50	% Pass #100	% Pass #200
Section 1	1	5.2	100	85	72	47	34	28	24	17	9	5.1
	2	5.3	100	89	75	50	37	30	26	19	9	5.4

	3	5.4	100	87	74	51	37	30	26	19	9	5.6
Section 2	4	5.2	100	88	72	50	37	30	26	19	9	5.5
	5	4.8	100	82	69	48	35	28	24	17	9	5.4
	6	5.3	100	87	74	51	38	31	27	20	11	6.5
Section 3	7	5.3	100	85	73	51	37	30	26	19	10	6.1
	8	5.1	100	84	72	51	37	30	26	18	9	5.5
	9	5.0	100	86	74	49	36	29	26	19	9	5.6
Section 4	10	5.1	100	88	74	51	37	30	26	19	9	5.7
	11	5.4	100	87	76	52	38	31	27	19	10	5.8
	12	5.1	100	86	73	49	36	30	26	19	10	5.9

Table 7. Averages and standard deviations for field cores test values

Section ID	**Descriptive Statistic**	**% Asphalt Cement**	**% Pass ¾”**	**% Pass ½”**	**% Pass 3/8”**	**% Pass #4**	**% Pass #8**	**% Pass #16**	**% Pass #30**	**% Pass #50**	**% Pass #100**	**% Pass #200**
Section 1	Average	5.3	100	87	74	49	36	29	26	18	9	5.4
	Std.	0.1	0	2.2	1.2	2.1	1.8	1.6	1.4	0.9	0.4	0.2
Section 2	Average	5.1	100	85	72	50	36	30	26	19	10	5.8
	Std.	0.3	0	3.1	2.3	1.7	1.3	1.3	1.1	1.1	0.9	0.6
Section 3	Average	5.1	100	85	73	50	36	30	26	19	9	5.7
	Std.	0.2	0	1.0	0.7	1.2	0.9	0.5	0.4	0.5	0.4	0.3
Section 4	Average	5.2	100	87	75	50	37	30	26	19	10	5.8
	Std.	0.1	0	1.3	1.7	1.4	0.7	0.5	0.4	0.2	0.1	0.1
Total	Average	5.2	100	86	73	50	37	30	26	19	9	5.7
	Std.	0.2	0	2.0	1.8	1.5	1.1	1.0	0.8	0.7	0.5	0.4

V. CRACK SURVEYS & DESCRIPTIONS

CRACK SURVEYS

Data Collection and Availability

Crack surveys were performed on 10/22/2013 and 4/24/2014. The crack surveys required measuring the distance of every visible major transverse thermal crack from the starting point at Station 989+95. These measurements were done using a surveyor's "walking wheel," with a precision of about ± 2 foot over the mile-long experimental section.

These crack location determinations were made while walking in the right shoulder of the southbound lanes. Most of the transverse cracks were found to be skewed to the roadway centerline. Therefore, the location of each transverse crack was noted on the field data sheet as the location of the right end of the crack. Also noted was whether the right or left end of the crack was skewed forward ("right forward" or "left forward" skew) or not skewed. Thus individual natural cracks were classified as either a right forward type, a left forward type, or a no-skew type.

The locations of all precut cracks were also determined as part of the 2013 and 2014 surveys. This was done, in part, for the purpose of making sure that the walking wheel was giving accurate locations over the entire survey mile. All precut cracks were found to be at the locations listed by AKDOT&PF engineers after construction. Using the measuring wheel, they were found to be within 2' or less of the listed locations throughout the entire mile. Precut cracks were no-skew types.

Raw data obtained during the research project is contained in Appendix B. Items of raw data pertinent to the experimental section include:

1. Locations of all natural transverse thermal cracks prior to construction
2. Locations of all transverse cracks precut during construction
3. Crack survey data obtained on 10-22-2013 and 4-24-2014
4. Simple descriptive statistics provided for Items 1 and 3

Analysis of Crack Survey Data

At the start of this report section it is important to note the distinction between the precut cracks and natural cracks discussed later. As used here the term “natural crack” refers to those transverse cracks that extend across the **full width** of the paved surface and are **not precut**. Precut cracks that have already (or will) become active are of course involve in the natural cracking process, but they are not considered natural cracks per se. The difference is discussed and photo-illustrated in *Crack Descriptions* section. The authors consider precut cracks—whether active or not—to be a pavement design feature and not a form of damage. Limited evidence so far in Alaska suggests that precut transverse cracks may need no maintenance sealing/filling for the life of the pavement. Therefore, the purpose of this analysis is to determine the extent to which various precut designs are able to limit, i.e., control development of natural thermal cracking not associated with the precut cracks.

A comparison is made between the frequency of preconstruction natural transverse thermal cracking and the frequency of natural transverse cracks observed during the 2013 and 2014 surveys. Data from these surveys is tabulated in Table 8.

According to Table 8, several significant findings can be noted just two years after construction of the experimental section:

- Before 2012 construction, the number of natural transverse cracks in all four subsections was similar—22, 17, 17, and 18 in subsections 1 through 4 respectively. Surprisingly, in just the two years since construction, the crack counts in subsections 1, 2, and 3 have actually increased beyond the preconstruction count.
    - By the time of the 4-24-2014 survey, the natural transverse crack count in **subsection 1** (the control) had increased by 77% over the preconstruction number.
    - By the 4-24-2014 survey, the natural transverse crack count in **subsection 2** had increased by 23% over the preconstruction number.
    - By the 4-24-2014 survey, the natural transverse crack count in **subsection 3** had increased by 23% over the preconstruction number.
- By 4-24-2014, only the natural transverse crack count in **subsection 4** was still lower than the preconstruction number—17% lower than the count prior to the repaving job. The subsection 4 precut design approach appears quite superior to the subsection 2 and 3 designs.

Table 8. Natural crack spacing and counts from field surveys

	Preconstruction Natural Cracking	Post-Construction Natural Cracking	
		From 2013 Survey	From 2014 Survey
ALL SUBSECTIONS INCLUDED			
Average Natural Crack Spacing	72.9	67.1	55.4
Standard Deviation of Spacing	32.9	46.4	41.8
Total Number of Natural Transverse Cracks	74	81	98
SUBSECTION 1 (Control)			
Average Natural Crack Spacing	60.8	42.1	34.4
Standard Deviation of Spacing	21.4	9.6	10.6
Total Number of Natural Transverse Cracks	22	32	39
SUBSECTION 2 (spacing 25')			
Average Natural Crack Spacing	80.8	77.4	58.1
Standard Deviation of Spacing	30.3	42.9	39.0
Total Number of Natural Transverse Cracks	17	17	22
SUBSECTION 3 (spacing 40')			
Average Natural Crack Spacing	74.5	71.7	60.8
Standard Deviation of Spacing	33.2	36.6	29.7
Total Number of Natural Transverse Cracks	17	18	22
SUBSECTION 4 (cuts on existing cracks)			
Average Natural Crack Spacing	75.6	101.2	96.5
Standard Deviation of Spacing	39.0	78.4	70.8
Total Number of Natural Transverse Cracks	18	14	15

The question of how precut depth influences precut effectiveness is addressed in Table 9. Although Table 9 provides no definitive degree of evidence, it appears that the areas precut to depths of 1 inch or 1 ½ inch produced fewer natural transverse thermal cracks. By 2014, the 0.5 inch precut depth produced the highest number of natural transverse cracks in subsections 2, 3, and 4. The table suggests that there is some degree advantage to deeper precuts although there is no evidence that a 1 ½ inch cut depth is better than a 1 inch cut.

Table 9. Precut depth influence on observed natural cracking

	Natural Crack Count During Indicated Survey Years	
	2013	2014
Subsection 2 (spacing 25')		
0.5" Cut depth	7	9
1.0" Cut Depth	3	5
1.5" Cut Depth	6	7
Subsection 3 (spacing 40')		
0.5" Cut depth	5	9
1.0" Cut Depth	5	6
1.5" Cut Depth	4	5
Subsection 4 (cuts on existing cracks)		
0.5" Cut depth	6	6
1.0" Cut Depth	4	4
1.5" Cut Depth	4	4

In brief summary:

- The preconstruction thermal cracking condition of all of the four subsections was similar, i.e., before resurfacing construction and precutting.
- The control section has performed very significantly worse than the three precut subsections in terms of the appearance of new natural transverse thermal cracks.
- Except for subsection 4, the count of natural transverse thermal cracks to date is higher than it was before the 2012 construction project.
- Subsection 4 obviously exhibits the best thermal cracking performance to date. All precuts in this subsection were placed at the approximate locations of preconstruction natural cracks.
- There is a tenuous indication that the precut crack depths of 1 inch and 1 ½ inch have worked better than those of ½ inch depth.

Is there really less thermal cracking activity in some subsections than in other subsections? The authors conjecture that the thermal cracking process within all four subsections (just as before construction) probably remains much the same. The two likely reasons for the observations to date are:

- Thermal cracks that did not extend across the full width of the pavement were not counted in the surveys. Partial width cracks may lengthen in time to extend across the entire paved width, and therefore eventually be counted as additional natural transverse thermal cracks. No assumptions can be made in this regard because a long history of observations in Alaska have found that most partial width cracks never extend to full width.

- The natural cracking process is very likely to have activated a number of the precut cracks. It is highly possible that the precut slots themselves mask much of the natural thermal cracking activity. This is of course the intended purpose of precutting. Careful measurements of width variations of the precut slots throughout at least one annual temperature cycling would be required to define which precuts have become active. A set of measurements would be necessary for each precut, requiring much additional work.

Appendix C contains visual representations, i.e., "crack maps" comparing locations of preconstruction transverse thermal cracks with locations of natural (non-precut) transverse thermal cracks as of April 24, 2014. The crack maps are presented on four pages of the appendix. A separate page represents each of the experimental subsections.

CRACK DESCRIPTIONS

A general visual inspection of the four research subsections was done on October 2, 2014. At this time a series of photos were obtained to document the various kinds and condition of cracking observed. A brief written description of the thermal cracking characteristics at various locations of interest was made as well.

This early-fall 2014 experimental-site inspection revealed the presence of several characteristic crack types.

- Natural transverse thermal cracks
- Precut transverse cracks—non-active
- Precut transverse cracks—active
- Precut transverse cracks with partial capture of natural transverse cracks

Natural transverse thermal cracks (natural cracks) are the natural cracks that developed completely independent of any precutting, i.e., transverse thermal cracks as would be found on any other paved road in the general area. Photos of natural transverse thermal cracking at identified station locations are shown in Figure 8.

Figure 8. Natural transverse cracks at ~ Stations 999+27 (lt.) & 1029+13 (rt.)

It may be of interest to learn that natural transverse thermal cracks also commonly form in gravel roads. Evidence of such cracking is fleeting however because movement of loose aggregate surfacing material tends to fill and/or cover obvious signs of thermal cracking at the gravel road surface.

Precut transverse cracks—non-active (precut) are precut transverse cracks that have not been activated by intrusion of the natural thermal cracking process. In other words, a non-active precut crack is simply a slot that has been saw-cut across the pavement surface. In all precutting experiments done to date in Alaska, saw-cuts have not extended completely to the bottom of the pavement layer. Figure 9 shows a precut crack at about Station 1005+24 that is probably non-active and the hole left from core sample number 4. In the subsections where precutting was done (all subsections except control), pavement cores were obtained at precut locations.

Figure 9. Precut non-active crack at ~ Station 1005+24

Precut transverse cracks—active (precut active) are precut transverse cracks that have been activated by the intrusion of natural thermal cracking process. Upon activation by the natural thermal cracking process these cracks become, in effect, simply man-influenced natural thermal cracks. Figure 10 shows a precut crack at about Station 1036+31 that is probably active at the present time.

Figure 10. Precut active crack at ~ Station 1036+31

The experimental section’s pavement is only two years old at the time of this reporting. And at this time it is nearly impossible to visually differentiate between non-active and active precut cracks. Differences will likely become more perceptible in later years as active cracks mature and become obviously wider after periods of low temperature. Also, a narrow zone of pavement adjacent to (paralleling) a mature active crack should become slightly depressed with time.

In the case of a new pavement, the only sure way of discriminating between active and non-active precut cracks is to make repeated measurements of crack width. The widths of active cracks will cycle with long term temperature variations. While width variations of active cracks in recently constructed pavements may be slight, experience in the Fairbanks area (McHattie, 1980) indicated that annual width variations of ½ inch or more may be common for older pavements.

Precut transverse cracks with partial capture of natural transverse cracks (precut partial) are by far the most interesting cracking type seen within the experimental subsections. Such precut cracks appear to be partially active and partially non-active—both conditions in the same crack! In instances where natural cracking occurs fairly close to a precut crack (apparently within about 4 to 6 feet), one or more portions of the natural crack may intersect with the precut crack and become integrated with it for some portion of the precut crack's length. Figure 11 shows two locations where the precut crack has partially captured the natural crack.

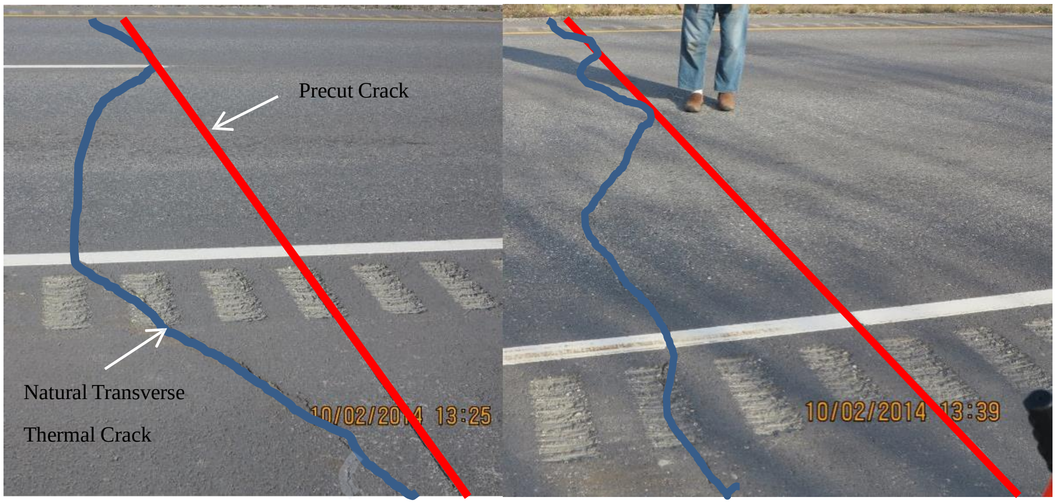


Figure 11. Precut cracks with partial capture of natural cracks at ~ Stations 1013+62 (lt.) & 1021+76 (rt.)

Some of the partial capture occurrences appeared to be interestingly complex, where the natural crack entered and exited the precut crack sometimes two or, in one observed case, three times. Studying the mechanics involved in the partial capture phenomenon might contribute to a better understanding of thermal cracking.

Resurfacing construction on the Richardson Highway MP 340–346 project required only surficial processing (reclaiming) of the top few inches of the pavement structure. The previously existing pattern of major transverse thermal cracking was allowed to remain in place, eventually covered only by two inches of new asphalt concrete and a few inches of reprocessed old pavement—perhaps 6 inches total new material placed atop the old crack pattern. The 10/02/2014 visual assessment suggests that—given this type of construction—the desired precutting effect, i.e., complete capture of subsequent natural cracking, requires that the precuts be placed as closely over the previously existing transverse cracking pattern as possible. This was strongly demonstrated in Subsection 4. In Subsection 4 precuts were placed nominally at the locations of the preexisting transverse cracks. Nominally in this case means that each precut in Subsection 4 would be centered at the mid-length point of the old crack, although actually precut perpendicular to the centerline. Thus the new precut did not exactly follow the existing thermal crack if the existing crack had a complicated shape and/or was skewed to the centerline. In Subsection 4 most of the precut cracks seem to have either partially or fully captured the subsequent natural cracks. The assumption at this point is that, had the Subsection 4 precut cracks more exactly traced the existing thermal cracks, the success rate of total captures for the precuts would have been much higher.

VI. NUMERICAL ANALYSES

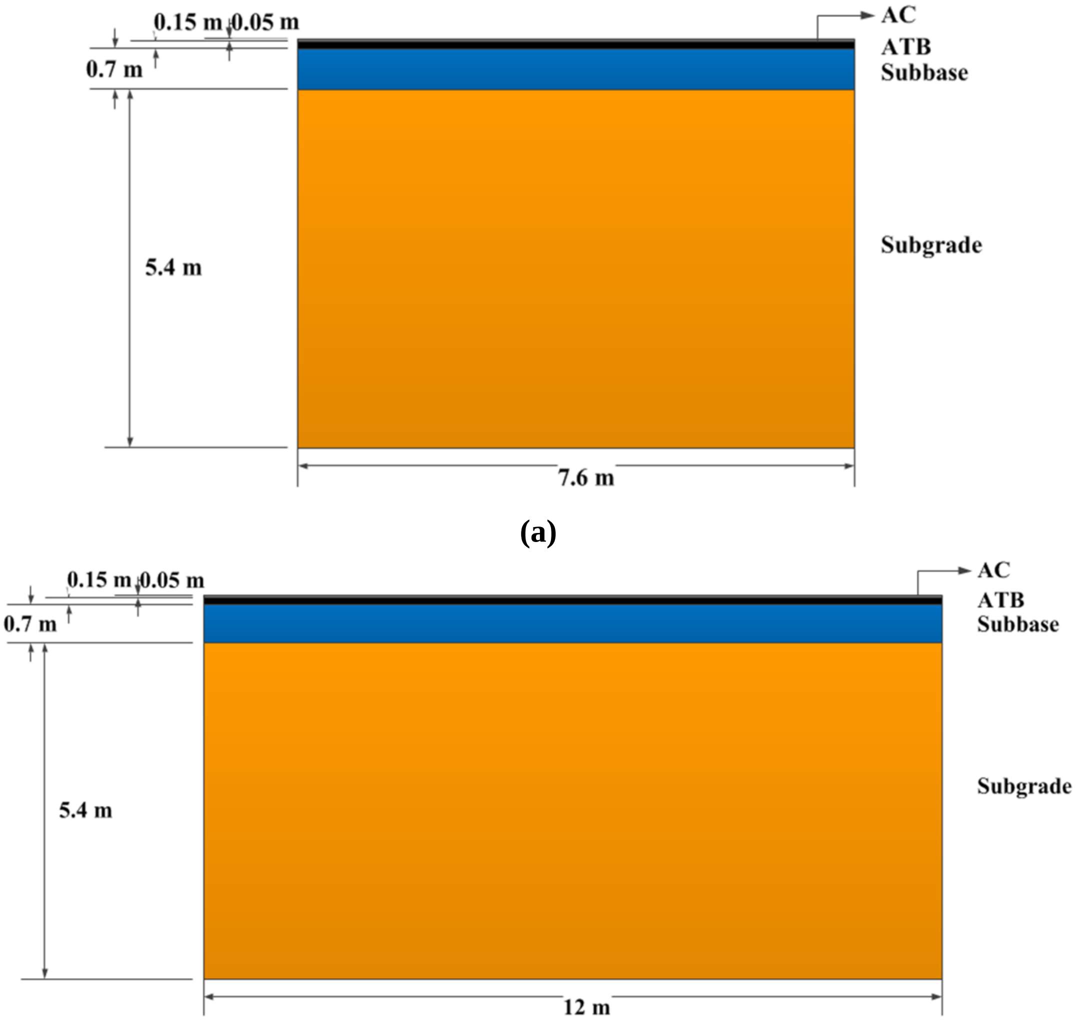
As discussed in Chapter III, the field test section was composed of four subsections, including control sections (without saw cuts), sections with 25’ (7.6 m) and 45’ (12 m) spacings and sections with cuts located over existing cracks. The experimental cuts were made at various depths (0.5’’, 1.0’’ and 1.5’’). ABAQUS – a FEM software package was utilized to facilitate the simulation.

SIMULATION CONFIGURATIONS AND INPUTS

FEM Model Configurations

In order to keep units consistent, all the geometry and input data have been converted with SI units. Figure 12 shows the schematic plots of the simulation sections. A typical pavement structure composted of four layers was used, and these four layers included 2 in. (0.05 m) of AC, 6 in. (0.15 m) of asphalt treated base (ATB), 2.30 feet (0.7 m) of subbase, and 17.06 feet (5.2 m) of subgrade.

Table 10 gives the summary of the simulated models. The aim of simulation is to evaluate the effect of cutting spacing and depth on the pavement stress distribution. There are two types of spacing, including 25’ section and 40’ section. Without any treatment thermal cracks randomly occur on the road surface when stresses built up exceed critical stress (strength). The intention to apply pre-cut technique was to proposedly create high stress concentration at the pre-cut tip (location) and reduce stress anywhere else to a level lower than its critical stress. Therefore, during the simulation, a possible thermal crack was set to be 0.04’’ (1 mm) wide and 0.2’’ (5 mm) deep as the reference. And the saw cut was set to be 0.12’’ (3 mm) wide with various cutting depths of 0.5’’, 1.0’’ and 1.5’’ (12.7 mm, 25.4 mm and 38.1 mm).



(a)

(b)

Figure 12. Schematic plots of simulation sections

Table 10. FEM modeling cases

Case	Section Spacing	Cut Depth (in)	Case	Section Spacing	Cut Depth (in)
1	25'	-	5	40'	-
2	25'	0.5	6	40'	0.5
3	25'	1.0	7	40'	1.0
4	25'	1.5	8	40'	1.5

Figure 13 shows a typical example of the FEM model with mesh grid near the saw cutting area and the possible thermal crack location. Since the areas near these two locations are critical, it is necessary to generate a biased or denser mesh grid at critical areas. The element shape used was quad shape with coupled temperature – displacement type.

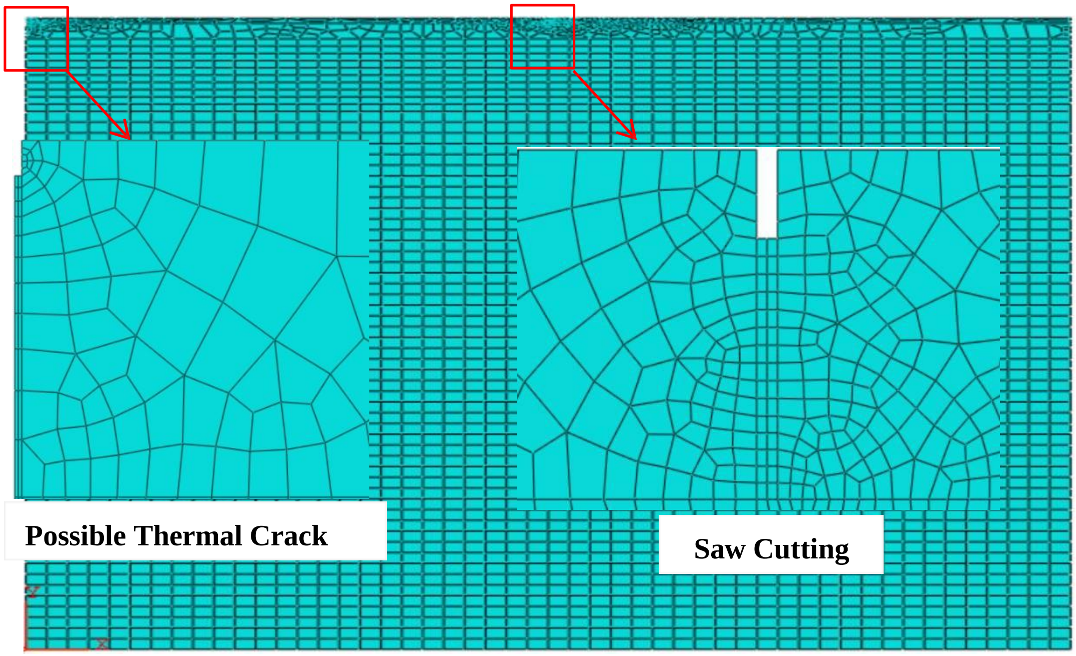


Figure 13. FEM model with mesh grid

Simulation Inputs

Table 11 lists all mechanical and thermal parameters used in the simulation. The moduli of AC and ATB base are temperature-dependent. However, they were kept constant to simplify the analysis. The boundary condition at the bottom was set to be 2 °C throughout the time domain. The average daily temperature data over the last 30 years was adopted to simulate the temperature variation at the surface of the AC layer for a total time period of two years, as shown in Figure 14. The temperature data can be accessed through Western Regional Climate Center (WRCC). It is assume that after one year, the affection of initial temperature condition can be neglected.

Table 11. Mechanical and thermal parameters

	AC	ATB Base	Subbase	Subgrade
Thickness (m)	0.05	0.15	0.70	5.20
E ($\times 10^3$ MPa)	3.516	1.724	0.275	0.069
Poisson’s Ratio	0.3	0.35	0.4	0.45
Density ($\times 10^3$ kg/m^3)	2.40	2.40	2.65	2.80
Thermal Conductivity ($\times 10^6$ J/day·m·°C)	1.296	1.296	0.605	1.443
Specific Heat ($\times 10^3$ J/kg·°C)	0.920	0.920	0.920	0.837
Coefficient of Thermal Expansion ($\times 10^{-6}$/°C)	30	30	12	5

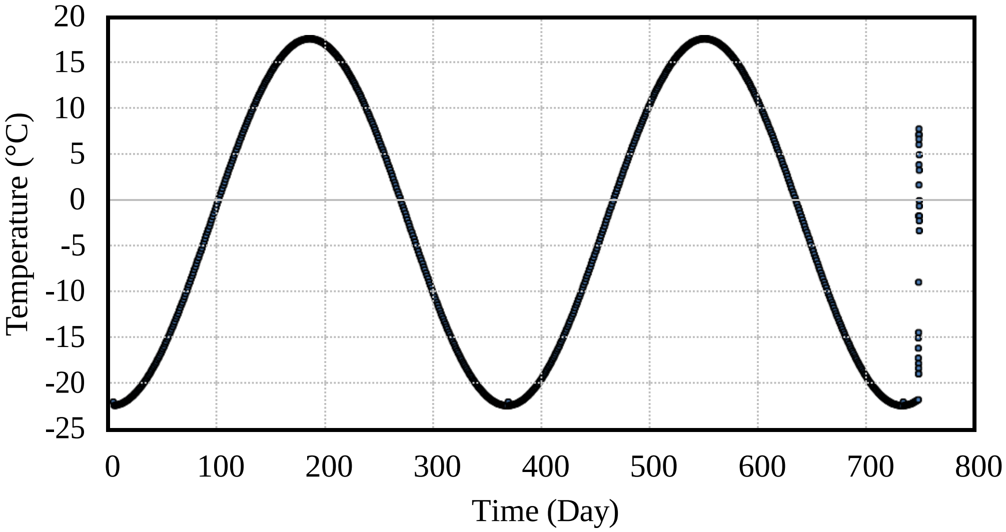
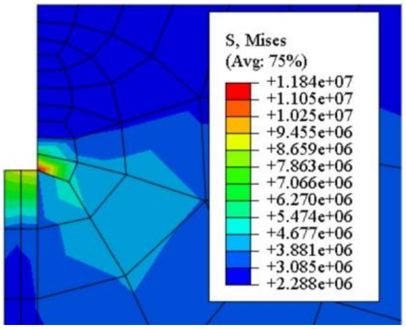


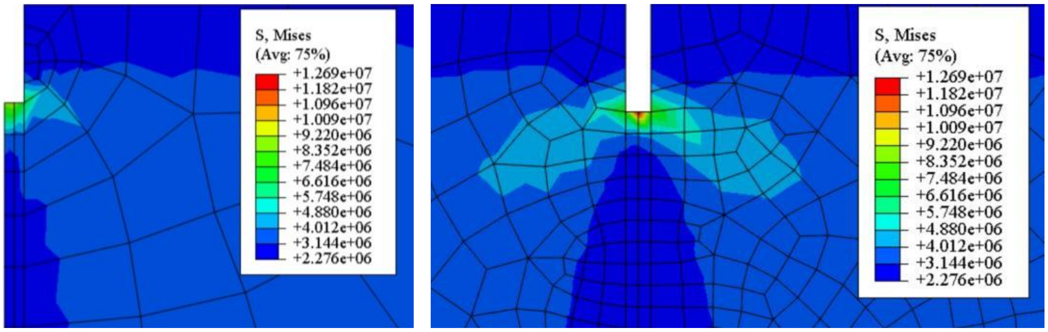
Figure 14. Average daily temperature data near experimental section

SIMULATION RESULTS AND ANALYSIS

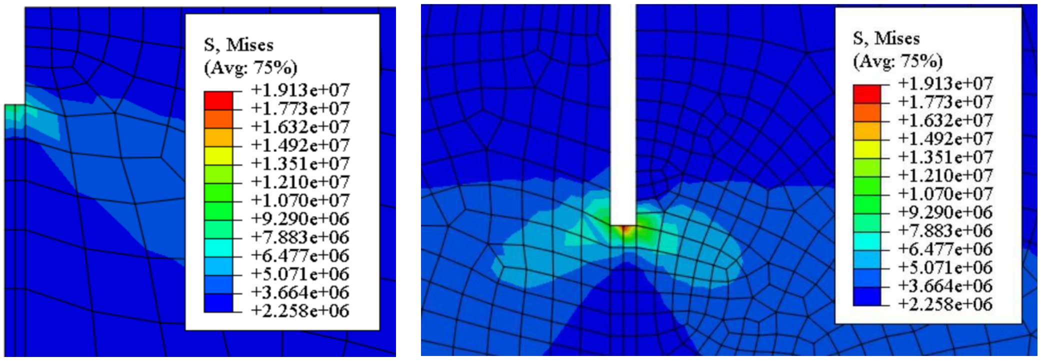
To illustrate the distribution of Mises stress near the possible thermal crack and saw cutting areas, the result of AC layer was extracted from the database of calculated FEM simulation results. The stress distribution is illustrated by a color contour. The color scale is on the right of each figure with magnitudes. Here models with 25' spacing were used in Figure 15 as examples to demonstrate the simulation results indicated by Mises stress distribution.



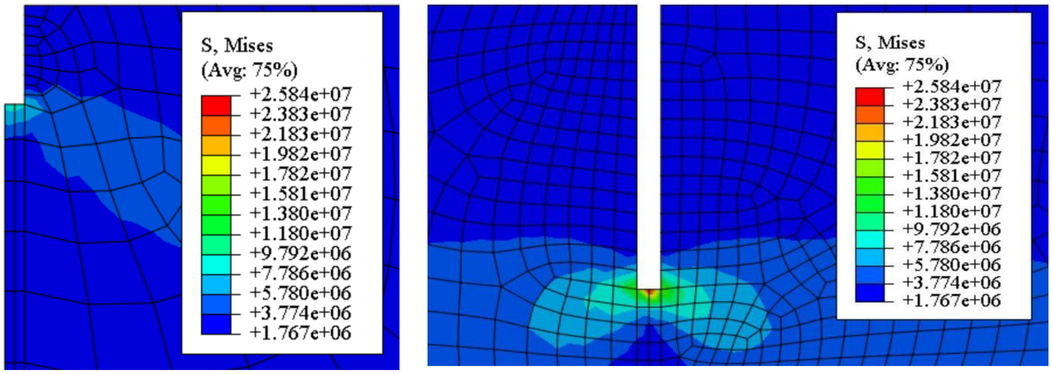
(a) 25’ spacing without saw cut



(b) 25’ spacing with 0.5’’ saw cutting depth



(c)) 25’ spacing with 1.0’’ saw cutting depth



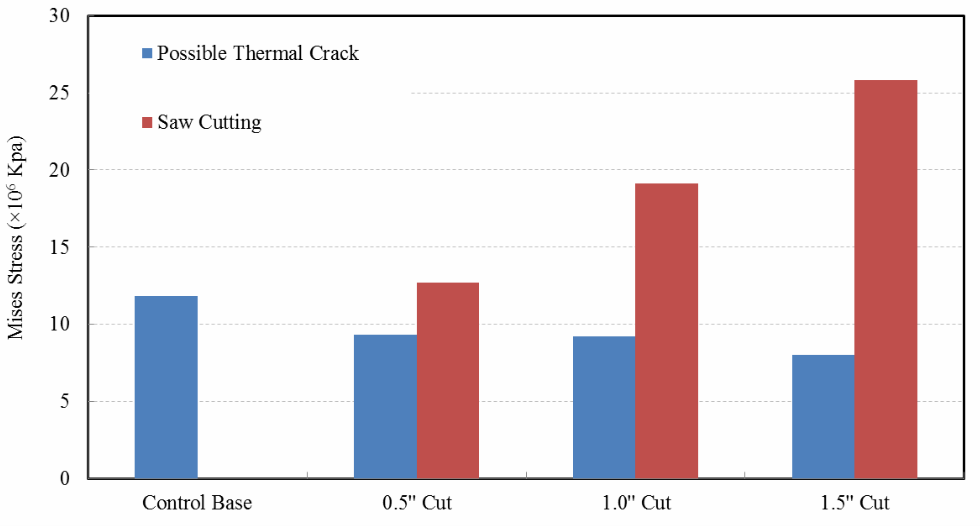
(d) 25’ spacing with 1.5’’ saw cutting depth

Figure 15. Stress distributions for 25’ spacing

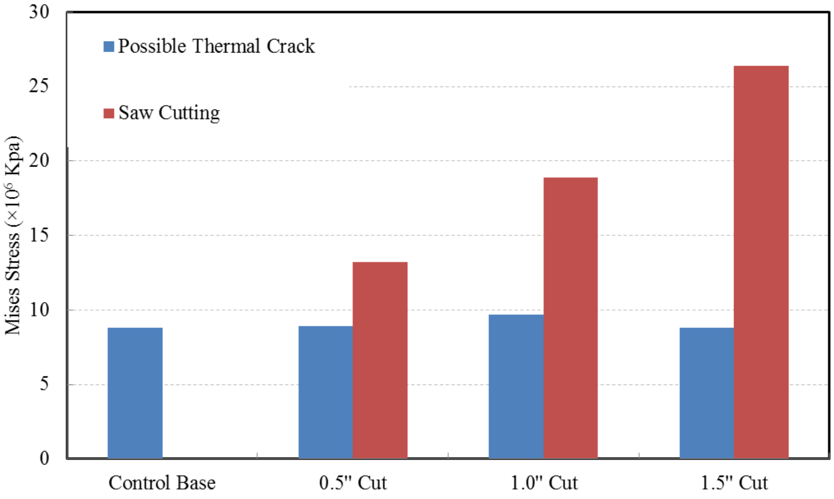
Figure 15(a) shows the maximum stress for 25’ spacing without saw cut was 1.18×10^7 kPa. It can be noticed from Figure 15(b)-(d) that the stress concentration occurred at the tip of saw cutting location. In addition, the maximum stress at the tip of the saw cutting location increased with the increase of saw cut depth (from 0.5’’, 1.0’’ and 1.5’’).

Figure 16 summarizes simulation results of all cases. Figure 16(a) gives the maximum stresses at the locations of both possible thermal crack and saw cutting areas for 25’ spacing sections. With the increase of cutting depth, the maximum stress at the bottom of the cutting tip increased dramatically while the stress at possible thermal crack location decreased. It is more likely to expect that crack occurs at the saw cutting location. This indicated that pre-cutting technique helped induce stress concentration (highest stress) and reduce stress anywhere else. In addition, increasing the cutting depth performed better in terms of controlling random occurrence of crack, which was consistent with the findings from the field observation in Chapter V.

Figure 16 (b) gives the maximum stresses at the locations of both possible thermal crack and saw cutting areas for 40’ spacing sections. Similar to the case for 25’ spacing, at 40’ spacing, the maximum stress at the bottom of the cutting tip increased significantly with the increase of cutting depth. However, the reduction of stress at the bottom of the possible thermal crack location was not as significant as that for 25’ spacing. This was also consistent with preliminary findings from the field observation which showed 25’ spacing was more effective than 40’ spacing with less amount of cracks occurred.



(a) 25’ Spacing



(b) 40’ Spacing

Figure 16. Summary of simulation results

VII. CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS

Precutting technology has been shown to work well in cases where roadway construction has included placement of at least several feet of new material. This has been demonstrated in Minnesota as well as by the 30-year-old test section at Fairbanks, Alaska.

With the caveat that the Richardson Highway experimental section reported herein has been monitored for only two years, this research tentatively indicates that precutting can significantly benefit the thermal crack performance of a pavement resurfacing project.

The best performing experimental precut subsection was where each precut was placed at the location of a transverse thermal crack that existed prior to reconstruction and repaving. This makes much sense according to the literature review and in view of long term observations at many locations in Alaska. Many years of Alaska experience has absolutely confirmed that full-width “major” transverse thermal cracks extend into the aggregate materials as much as several feet below the bottom of the AC pavement. In Alaska it is known that the pattern of transverse thermal cracking continues to exist within underlying materials whenever construction involves only the upper few inches of an existing, thermal cracked pavement structure.

IMPLEMENTATION RECOMMENDATIONS

Implementation Recommendation 1 — Continue trials of precutting on pavement resurfacing jobs.

Implementation Recommendation 2 — When repaving is part of a construction project that involves less than two feet of pavement structural reconditioning, always position precuts as close as possible to follow the general location and skew of the previously existing natural thermal crack. The precut should be made as one straight “best-fit” line without regard to bifurcations or doglegging of the preexisting natural crack.

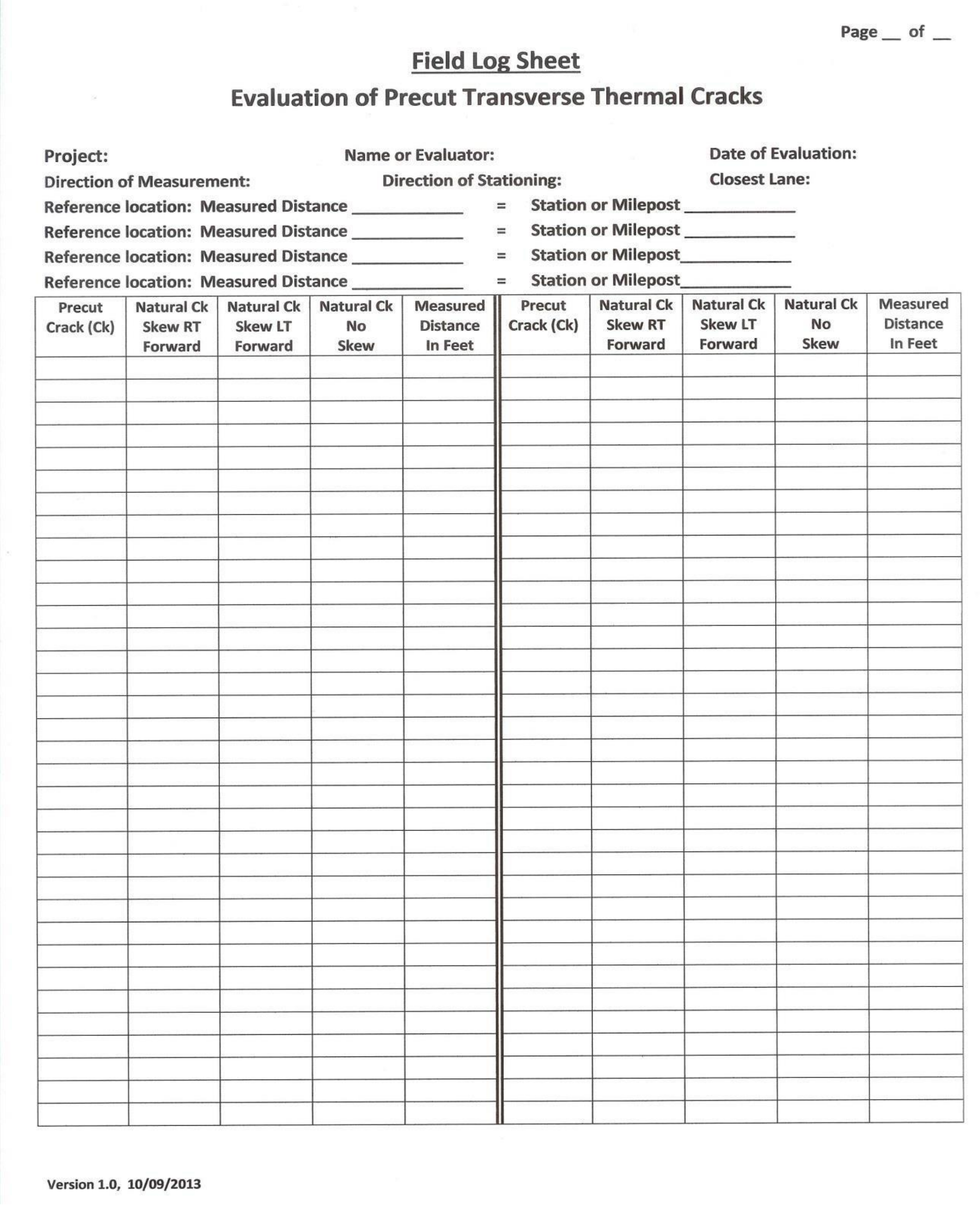
Implementation Recommendation 3 — If implementation item 2 is followed, an accurate mapping of existing natural transverse thermal cracks absolutely must be done before reconstruction begins.

RECOMMENDATIONS FOR CONTINUING RESEARCH

- Generally continue along the promising line of research covered in this report.
- Continue to survey the four experimental Richardson Highway subsections discussed in this report.
- Develop a rapid way of determining whether the precut thermal cracks have become active or not. Perhaps this could be done by means of probing, wintertime thermal infrared sensing, or ground penetrating radar.
- Combine tests of the precutting with field trials of minimizing or eliminating crack sealing. The non-active precut cracks do not need sealing, and it is also very likely that active precut cracks require no seals.

APPENDIX A: EXAMPLES OF CRACK SURVEY SHEETS

Appndix A1. Sample of blank field data sheet



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Field Log Sheet

Evaluation of Precut Transverse Thermal Cracks

Project: **Name or Evaluator:** **Date of Evaluation:**

Direction of Measurement: **Direction of Stationing:** **Closest Lane:**

Reference location: Measured Distance _____________ = **Station or Milepost** _____________

Reference location: Measured Distance _____________ = **Station or Milepost** _____________

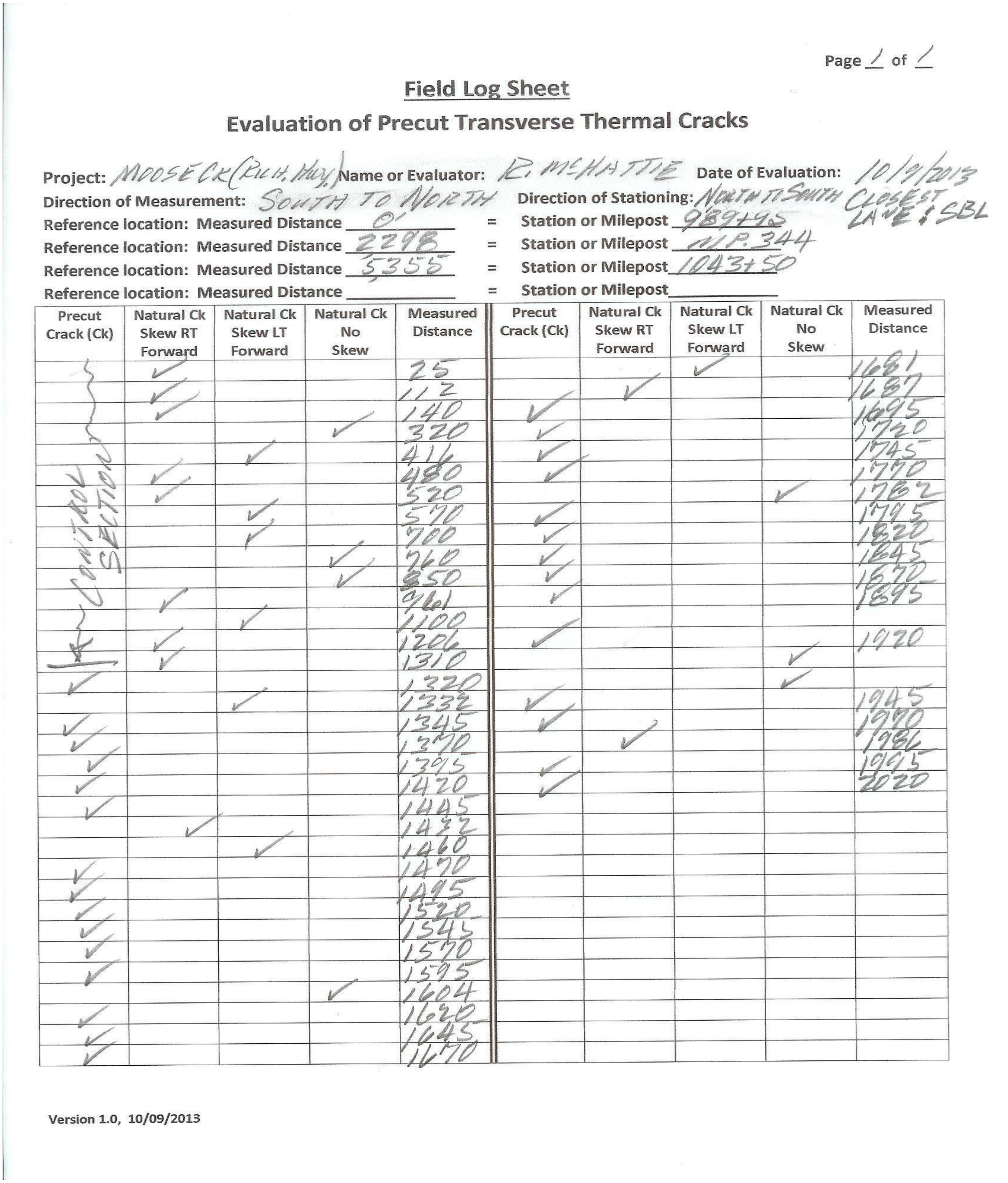
Reference location: Measured Distance _____________ = **Station or Milepost**_____________

Reference location: Measured Distance _____________ = **Station or Milepost**_____________

Precut Crack (Ck)	Natural Ck Skew RT Forward	Natural Ck Skew LT Forward	Natural Ck No Skew	Measured Distance In Feet	Precut Crack (Ck)	Natural Ck Skew RT Forward	Natural Ck Skew LT Forward	Natural Ck No Skew	Measured Distance In Feet

Version 1.0, 10/09/2013

Appendix A2. Example of completed field data sheet



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Field Log Sheet

Evaluation of Precut Transverse Thermal Cracks

Project: MOOSE CK (RICH. HWY) **Name or Evaluator:** R. McHATTIE **Date of Evaluation:** 10/9/2013
Direction of Measurement: SOUTH TO NORTH **Direction of Stationing:** NORTH TO SOUTH CLOSEST LANE & SBL
Reference location: Measured Distance 0' = **Station or Milepost** 989+95
Reference location: Measured Distance 2298 = **Station or Milepost** M.P. 344
Reference location: Measured Distance 5355 = **Station or Milepost** 1043+50
Reference location: Measured Distance ____ = **Station or Milepost** ____

Precut Crack (Ck)	Natural Ck Skew RT Forward	Natural Ck Skew LT Forward	Natural Ck No Skew	Measured Distance	Precut Crack (Ck)	Natural Ck Skew RT Forward	Natural Ck Skew LT Forward	Natural Ck No Skew	Measured Distance
CONTROL SECTION	✓			25			✓		1681
	✓			112		✓			1687
	✓			140	✓				1695
			✓	320	✓				1720
		✓		411	✓				1745
	✓			480	✓				1770
	✓			520				✓	1782
		✓		570	✓				1795
		✓		700	✓				1820
			✓	760	✓				1845
			✓	850	✓				1870
	✓			961	✓				1895
		✓		1100					
	✓			1206	✓				1920
	✓			1310				✓	
✓				1320				✓	
		✓		1332	✓				1945
✓				1345	✓				1970
✓				1370		✓			1986
✓				1395	✓				1995
✓				1420	✓				2020
✓				1445					
	✓			1432					
		✓		1460					
✓				1470					
✓				1495					
✓				1520					
✓				1545					
✓				1570					
✓				1595					
			✓	1604					
✓				1620					
✓				1645					
✓				1670					

Version 1.0, 10/09/2013

APPENDIX B: RAW CRACK SURVEY DATA

Appendix B1. Preconstruction transverse crack locations

Points below are the Location of the surface Cracks from edge of Pavement to edge of Pavement of the Richardson Highway Between MP 340 and 346 (Southbound Prism)

Surface Crack Location Prior to Resurfacing

LEFT			Right			
Station	Feet from Sta 989+95		Station	Feet from Sta 989+95	Distance Between	Subsection Number
990+20 L	25		990+24 R	29		1
990+74 L	79		990+74 R	79	50	1
991+29 L	134		991+31 R	136	57	1
991+80 L	185		991+82 R	187	51	1
992+26 L	231		992+31 R	236	49	1
993+36 L	341		993+36 R	341	105	1
993+77 L	382		993+77 R	382	41	1
994+15 L	420		994+15 R	420	38	1
994+87 L	492		994+92 R	497	77	1
995+43 L	548		995+43 R	548	51	1
996+27 L	632		996+29 R	634	86	1
996+72 L	677		996+74 R	679	45	1
997+42 L	747		997+42 R	747	68	1
997+60 L	765		997+65 R	770	23	1
998+21 L	826		998+30 R	835	65	1
999+13 L	918		999+11 R	916	81	1
999+76 L	981		999+66 R	971	55	1
1000+58 L	1063		1000+58 R	1063	92	1
1001+14 L	1119		1001+08 R	1113	50	1
1001+59 L	1164		1001+64 R	1169	56	1
1002+07 L	1212		1002+05 R	1210	41	1
1003+04 L	1309		1003+01 R	1306	96	1
1003+34 L	1339		1003+38 R	1343	37	2
1003+95 L	1400		1003+93 R	1398	55	2
1004+52 L	1457		1004+60 R	1465	67	2
1005+19 L	1524		1005+18 R	1523	58	2
1005+89 L	1594		1005+89 R	1594	71	2
1006+97 L	1702		1006+96 R	1701	107	2
1007+98 L	1803		1007+98 R	1803	102	2
1008+98 L	1903		1009+02 R	1907	104	2
1009+75 L	1980		1009+77 R	1982	75	2
1011+04 L	2109		1011+05 R	2110	128	2
1011+70 L	2175		1011+70 R	2175	65	2
1012+09 L	2214		1012+07 R	2212	37	2
1012+49 L	2254		1012+49 R	2254	42	2
1013+37 L	2342		1013+37 R	2342	88	2
1014+57 L	2462		1014+62 R	2467	125	2
1015+81 L	2586		1015+83 R	2588	121	2
1016+29 L	2634		1016+31 R	2636	48	2

Appendix B2. Preconstruction transverse crack locations (continued)

1017+08 L	2713	1017+01 R	2706	70	3
1018+35 L	2840	1018+35 R	2840	134	3
1018+74 L	2879	1018+76 R	2881	41	3
1019+43 L	2948	1019+37 R	2942	61	3
1019+83 L	2988	1019+84 R	2989	47	3
1020+16 L	3021	1020+18 R	3023	34	3
1020+93 L	3098	1020+96 R	3101	78	3
1021+56 L	3161	1021+52 R	3157	56	3
1022+88 L	3293	1022+85 R	3290	133	3
1023+67 L	3372	1023+68 R	3373	83	3
1024+42 L	3447	1024+43 R	3448	75	3
1025+45 L	3550	1025+45 R	3550	102	3
1026+26 L	3631	1026+34 R	3639	89	3
1027+22 L	3727	1027+16 R	3721	82	3
1028+03 L	3808	1028+05 R	3810	89	3
1028+12 L	3817	1028+15 R	3820	10	3
1028+94 L	3899	1028+93 R	3898	78	3
1030+56 L	4061	1030+59 R	4064	166	4
1031+86 L	4191	1031+76 R	4181	117	4
1032+79 L	4284	1032+76 R	4281	100	4
1033+63 L	4368	1033+62 R	4367	86	4
1034+24 L	4429	1034+23 R	4428	61	4
1035+09 L	4514	1035+06 R	4511	83	4
1036+11 L	4616	1036+10 R	4615	104	4
1036+38 L	4643	1036+33 R	4638	23	4
1037+96 L	4801	1037+96 R	4801	163	4
1038+93 L	4898	1038+95 R	4900	99	4
1039+16 L	4921	1039+17 R	4922	22	4
1040+09 L	5014	1040+10 R	5015	93	4
1040+40 L	5045	1040+40 R	5045	30	4
1040+86 L	5091	1040+82 R	5087	42	4
1041+49 L	5154	1041+56 R	5161	74	4
1041+82 L	5187	1041+74 R	5179	18	4
1042+58 L	5263	1042+65 R	5270	91	4
1043+29 L	5334	1043+44 R	5349	79	4

Appendix B3. Basic statistics for preconstruction transverse cracks

Average Spacing	72.9	Total Section Count	74
Standard Deviation	32.9		

Subsection 4 Preconstruction Average	75.6	Subsection 4 Count	18
Subsection 4 Preconstruction Standard Deviation	39.0		
Subsection 3 Preconstruction Average	74.5	Subsection 3 Count	17
Subsection 3 Preconstruction Standard Deviation	33.2		
Subsection 2 Preconstruction Average	80.8	Subsection 2 Count	17
Subsection 2 Preconstruction Standard Deviation	30.3		
Subsection 1 Preconstruction Average	60.8	Subsection 1 Count	22
Subsection 1 Preconstruction Standard Deviation	21.4		

Appendix B4. Precut transverse crack locations for Subsection 2

Precut Locations Measured 04-24-2014								
Precut Crack	Natural Ck Skew RT Forward	Natural Ck Skew LT Forward	Natural Ck No Skew	Measured Distance in ft. from Sta. 989+95	Actual Spacing			Precut Depth (inches)
1				1322		SUBSECTION 2		0.5
1				1346	24			0.5
1				1372	26			0.5
1				1397	25			0.5
1				1422	25			0.5
1				1447	25			0.5
1				1472	25			0.5
1				1497	25			0.5
1				1522	25			0.5
1				1547	25			0.5
1				1572	25			0.5
1				1597	25			0.5
1				1622	25			0.5
1				1647	25			0.5
1				1672	25			0.5
1				1697	25			0.5
1				1722	25			1.0
1				1762	40			1.0
1				1787	25			1.0
1				1812	25			1.0
1				1837	25			1.0
1				1862	25			1.0
1				1887	25			1.0
1				1912	25			1.0
1				1937	25			1.0
1				1962	25			1.0
1				1987	25			1.0
1				2012	25			1.0
1				2037	25			1.0
1				2062	25			1.0
1				2087	25			1.0
1				2112	25			1.0
1				2137	25			1.0
1				2162	25			1.0
1				2202	40			1.5
1				2227	25			1.5
1				2252	25			1.5
1				2277	25			1.5
1				2302	25			1.5
1				2327	25			1.5
1				2353	26			1.5
1				2378	25			1.5
1				2403	25			1.5
1				2427	24			1.5
1				2453	26			1.5
1				2478	25			1.5
1				2502	24			1.5
1				2527	25			1.5
1				2552	25			1.5
1				2577	25			1.5
1				2602	25			1.5

Appendix B5. Precut transverse crack locations for Subsection 3

1				2642	40	SUBSECTION 3		0.5
1				2683	41			0.5
1				2722	39			0.5
1				2763	41			0.5
1				2803	40			0.5
1				2842	39			0.5
1				2881	39			0.5
1				2922	41			0.5
1				2962	40			0.5
1				3002	40			0.5
1				3042	40			0.5
1				3082	40			1.0
1				3123	41			1.0
1				3163	40			1.0
1				3203	40			1.0
1				3243	40			1.0
1				3283	40			1.0
1				3322	39			1.0
1				3363	41			1.0
1				3402	39			1.0
1				3443	41			1.0
1				3482	39			1.0
1				3522	40			1.5
1				3562	40			1.5
1				3602	40			1.5
1				3642	40			1.5
1				3682	40			1.5
1				3722	40			1.5
1				3762	40			1.5
1				3802	40			1.5
1				3842	40			1.5
1				3882	40			1.5
1				3922	40			1.5

Appendix B6. Precut transverse crack locations for Subsection 4

1				4065		SUBSECTION 4		0.5
1				4188		Intersection area		0.5
1				4221	33			0.5
1				4285	64			0.5
1				4370	85			0.5
1				4431	61			0.5
1				4457	26			0.5
1				4516	59			1.0
1				4540	24			1.0
1				4563	23			1.0
1				4618	55			1.0
1				4643	25			1.0
1				4668	25			1.0
1				4717	49			1.0
1				4748	31			1.0
1				4803	55			1.0
1				4901	98			1.0
1				4924	23			1.5
1				4967	43			1.5
1				5017	50			1.5
1				5047	30			1.5
1				5091	44			1.5
1				5160	69			1.5
1				5185	25			1.5
1				5240	55			1.5
1				5270	30			1.5
1				5344	74			1.5

Appendix B7. Crack survey results from 10-22-2013

Surface Crack Location on 10-22-2013

Precut Crack	Natural Ck Skew RT Forward	Natural Ck Skew LT Forward	Natural Ck No Skew	Measured Distance in ft. from Sta 989+95	Distance from Previous Crack	989+95	Subsection Number	Precut Depth	Number at Given Precut Depth
	×			11		990+06	1		
	×			42	31	990+37	1		
			×	96	54	990+91	1		
			×	152	56	991+47	1		
			×	201	49	991+96	1		
	×			250	49	992+45	1		
			×	292	42	992+87	1		
			×	319	27	993+14	1		
			×	355	36	993+50	1		
			×	397	42	993+92	1		
			×	434	37	994+29	1		
			×	470	36	994+65	1		
			×	511	41	995+06	1		
			×	561	50	995+56	1		
			×	599	38	995+94	1		
			×	647	48	996+42	1		
			×	691	44	996+86	1		
		×		730	39	997+25	1		
			×	759	29	997+54	1		
	×			782	23	997+77	1		
	×			810	28	998+05	1		
	×			848	38	998+43	1		
		×		897	49	998+92	1		
			×	930	33	999+25	1		
			×	984	54	999+79	1		
			×	1044	60	1000+39	1		
			×	1074	30	1000+69	1		
		×		1124	50	1001+19	1		
	×			1179	55	1001+74	1		
			×	1222	43	1002+17	1		
			×	1269	47	1002+64	1		
		×		1317	48	1003+12	1	0.5	
	×			1355	38	1003+50	2	0.5	
		×		1408	53	1004+03	2	0.5	
	×			1475	67	1004+70	2	0.5	7
			×	1533	58	1005+28	2	0.5	
			×	1606	73	1006+01	2	0.5	
		×		1640	34	1006+35	2	0.5	
			×	1710	70	1007+05	2		
	×			1916	206	1009+11	2	1	
	×			1991	75	1009+86	2	1	3
			×	2120	129	1011+15	2	1	
			×	2183	63	1011+78	2		
			×	2220	37	1012+15	2	1.5	
			×	2261	41	1012+56	2	1.5	
			×	2350	89	1013+45	2	1.5	6
	×			2415	65	1014+10	2	1.5	
	×			2476	61	1014+71	2	1.5	
			×	2594	118	1015+89	2	1.5	
		×		2713	119	1017+08	3		
	×			2802	89	1017+97	3	0.5	
			×	2847	45	1018+42	3	0.5	
			×	2888	41	1018+83	3	0.5	5
		×		2949	61	1019+44	3	0.5	
			×	2997	48	1019+92	3	0.5	
	×			3024	27	1020+19	3		
			×	3102	78	1020+97	3	1	
		×		3160	58	1021+55	3	1	
			×	3291	131	1022+86	3	1	5
			×	3374	83	1023+69	3	1	
			×	3449	75	1024+44	3	1	
		×		3493	44	1024+88	3		
			×	3551	58	1025+46	3	1.5	
		×		3721	170	1027+16	3	1.5	4
			×	3821	100	1028+16	3	1.5	
			×	3899	78	1028+94	3	1.5	
			×	3932	33	1029+27	3		
	×			4064	132	1030+59	4	0.5	
			×	4127	63	1031+22	4	0.5	
		×		4183	56	1031+78	4	0.5	6
	×			4222	39	1032+17	4	0.5	
			×	4283	61	1032+78	4	0.5	
	×			4315	32	1033+10	4	0.5	
		×		4511	196	1035+06	4	1	
		×		4710	199	1037+05	4	1	4
			×	4772	62	1037+67	4	1	
		×		4826	54	1038+21	4	1	
	×			5087	261	1040+82	4	1.5	
	×			5272	185	1042+67	4	1.5	4
	×			5343	71	1043+38	4	1.5	
			×	5379	36	1043+74	4	1.5	

Appendix B8. Basic statistics for 10-22-2013 crack survey

Average Spacing	67.1	Total Section Count	81
Standard Deviation	46.4		

Subsection 4 Postconstruction Average		101.2	Subsection 4 Count	14
Subsection 4 Postconstruction Standard Deviation		78.4		
Subsection 3 Postconstruction Average		71.7	Subsection 3 Count	18
Subsection 3 Postconstruction Standard Deviation		36.6		
Subsection 2 Postconstruction Average		77.4	Subsection 2 Count	17
Subsection 2 Postconstruction Standard Deviation		42.9		
Subsection 1 Postconstruction Average		42.1	Subsection 1 Count	32
Subsection 1 Postconstruction Standard Deviation		9.6		

Appendix B9. Crack survey results from 04-24-2014

Surface Crack Location on 04-24-2014

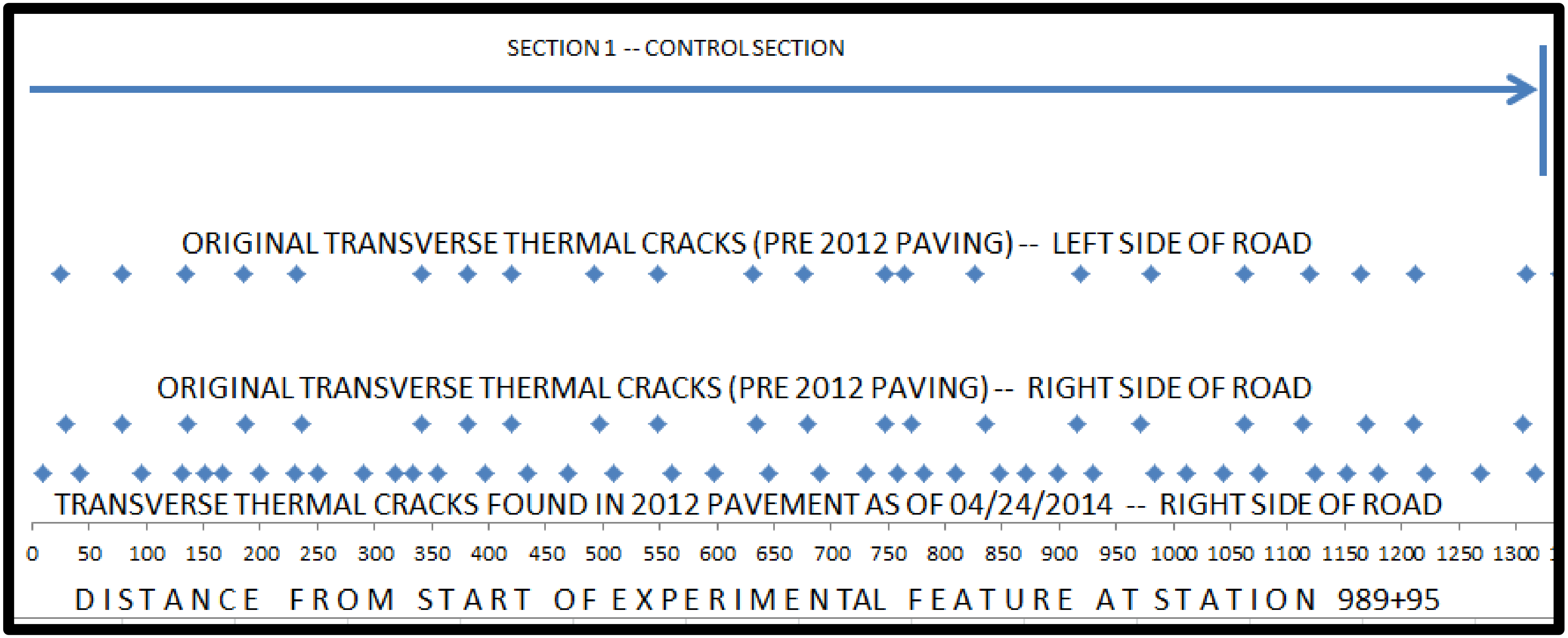
Precut Crack	Natural Ck Skew RT Forward	Natural Ck Skew LT Forward	Natural Ck No Skew	Measured Distance in ft. from Sta 989+95	Distance from Previous Crack		989+95	Subsection Number	Precut Depth	Number at Given Precut Depth
	x			10			990+05	1		
	x			42	32		990+37	1		
			x	96	54		990+91	1		
			x	132	36		991+27	1		
			x	151	19		991+46	1		
			x	167	16		991+62	1		
			x	200	33		991+95	1		
			x	230	30		992+25	1		
			x	250	20		992+45	1		
		x		291	41		992+86	1		
			x	318	27		993+13	1		
			x	333	15		993+28	1		
			x	355	22		993+50	1		
			x	397	42		993+92	1		
			x	434	37		994+29	1		
			x	469	35		994+64	1		
	x			510	41		995+05	1		
			x	561	51		995+56	1		
			x	598	37		995+93	1		
			x	646	48		996+41	1		
			x	690	44		996+85	1		
		x		730	40		997+25	1		
			x	758	28		997+53	1		
	x			782	24		997+77	1		
	x			809	27		998+04	1		
	x			847	38		998+42	1		
		x		871	24		998+66	1		
		x		898	27		998+93	1		
			x	929	31		999+24	1		
			x	984	55		999+79	1		
			x	1012	28		1000+07	1		
			x	1044	32		1000+39	1		
			x	1074	30		1000+69	1		
		x		1124	50		1001+19	1		
			x	1152	28		1001+47	1		
	x			1179	27		1001+74	1		
			x	1222	43		1002+17	1		
		x		1269	47		1002+64	1		
		x		1317	48		1003+12	1	0.5	
	x			1355	38		1003+50	2	0.5	
		x		1409	54		1004+04	2	0.5	
			x	1436	27		1004+31	2	0.5	
	x			1476	40		1004+71	2	0.5	9
			x	1533	57		1005+28	2	0.5	
		x		1565	32		1005+60	2	0.5	
			x	1606	41		1006+01	2	0.5	
		x		1641	35		1006+36	2	0.5	
			x	1711	70		1007+06	2		
	x			1916	205		1009+11	2	1	
	x			1949	33		1009+44	2	1	
	x			1992	43		1009+87	2	1	5
		x		2067	75		1010+62	2	1	
			x	2120	53		1011+15	2	1	
			x	2183	63		1011+78	2		
		x		2221	38		1012+16	2	1.5	
			x	2261	40		1012+56	2	1.5	
		x		2286	25		1012+81	2	1.5	
		x		2351	65		1013+46	2	1.5	7
	x			2416	65		1014+11	2	1.5	
	x			2474	58		1014+69	2	1.5	
	x			2595	121		1015+90	2	1.5	
			x	2680	85		1016+75	3	0.5	
	x			2698	18		1016+93	3	0.5	
		x		2713	15		1017+08	3	0.5	
	x			2803	90		1017+98	3	0.5	9
			x	2848	45		1018+43	3	0.5	
	x			2889	41		1018+84	3	0.5	
		x		2949	60		1019+44	3	0.5	
			x	2997	48		1019+92	3	0.5	
	x			3026	29		1020+21	3	0.5	
	x			3101	75		1020+96	3	1	
	x			3160	59		1021+55	3	1	
		x		3292	132		1022+87	3	1	6
			x	3375	83		1023+70	3	1	
	x			3425	50		1024+20	3	1	
	x			3450	25		1024+45	3	1	
		x		3494	44		1024+89	3		
			x	3552	58		1025+47	3	1.5	
	x			3642	90		1026+37	3	1.5	
		x		3722	80		1027+17	3	1.5	5
	x			3822	100		1028+17	3	1.5	
			x	3900	78		1028+95	3	1.5	
	x			3933	33		1029+28	3		
	x			4065	132		1030+60	4	0.5	
	x			4129	64		1031+24	4	0.5	
		x		4156	27		1031+51	4	0.5	6
		x		4184	28		1031+79	4	0.5	
	x			4224	40		1032+19	4	0.5	
	x			4316	92		1033+11	4	0.5	
		x		4513	197		1035+08	4	1	
		x		4712	199		1037+07	4	1	4
		x		4829	117		1038+24	4	1	
		x		4848	19		1038+43	4	1	
	x			5089	241		1040+84	4	1.5	
	x			5142	53		1041+37	4	1.5	4
	x			5273	131		1042+68	4	1.5	
	x			5344	71		1043+39	4	1.5	
			x	5381	37		1043+76	4		

Appendix B10. Basic statistics for 04-24-2014 crack survey

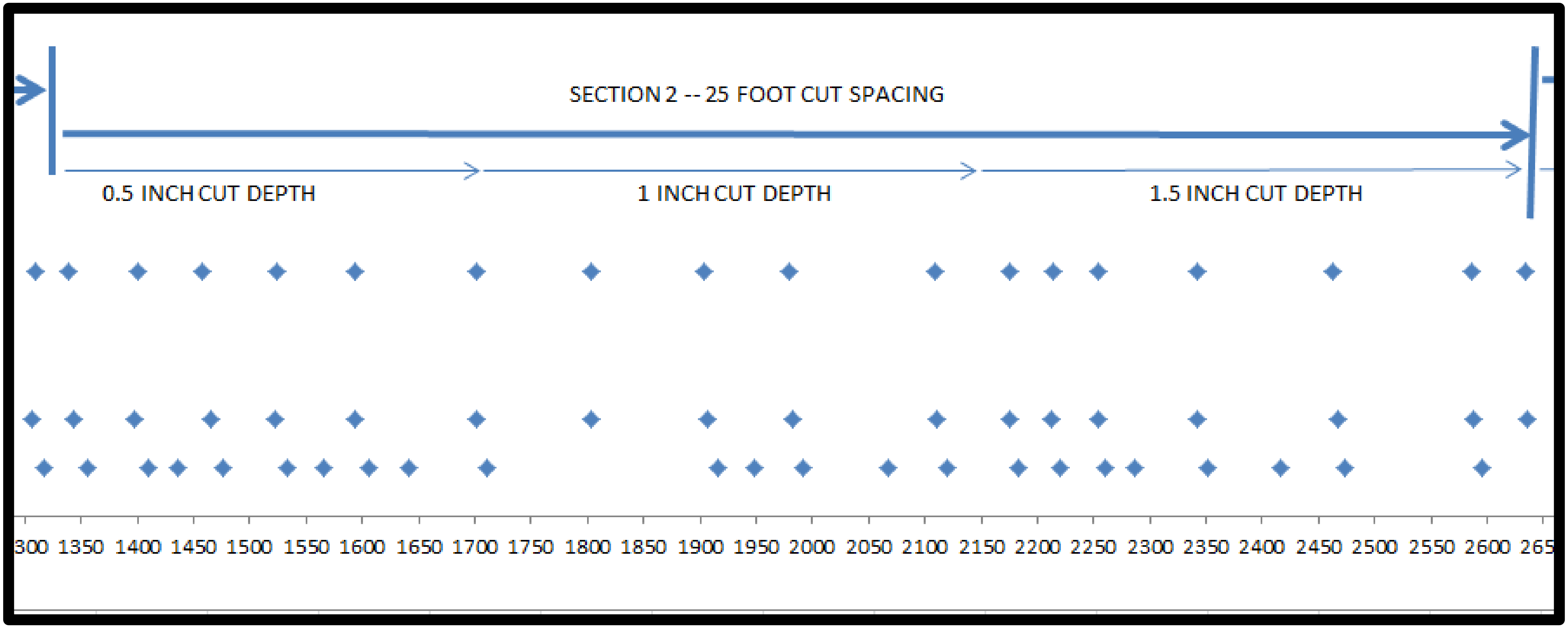
Average Spacing	55.4		Total Section Count	98
Standard Deviation	41.8			

Subsection 4 Postconstruction Average	96.5		Subsection 4 Count	15
Subsection 4 Postconstruction Standard Deviation	70.8			
Subsection 3 Postconstruction Average	60.8		Subsection 3 Count	22
Subsection 3 Postconstruction Standard Deviation	29.7			
Subsection 2 Postconstruction Average	58.1		Subsection 2 Count	22
Subsection 2 Postconstruction Standard Deviation	39.0			
Subection 1 Postconstruction Average	34.4		Subsection 1 Count	39
Subsection 1 Postconstruction Standard Deviation	10.6			

APPENDIX C: CRACK MAP BASED ON 2014 FIELD DATA

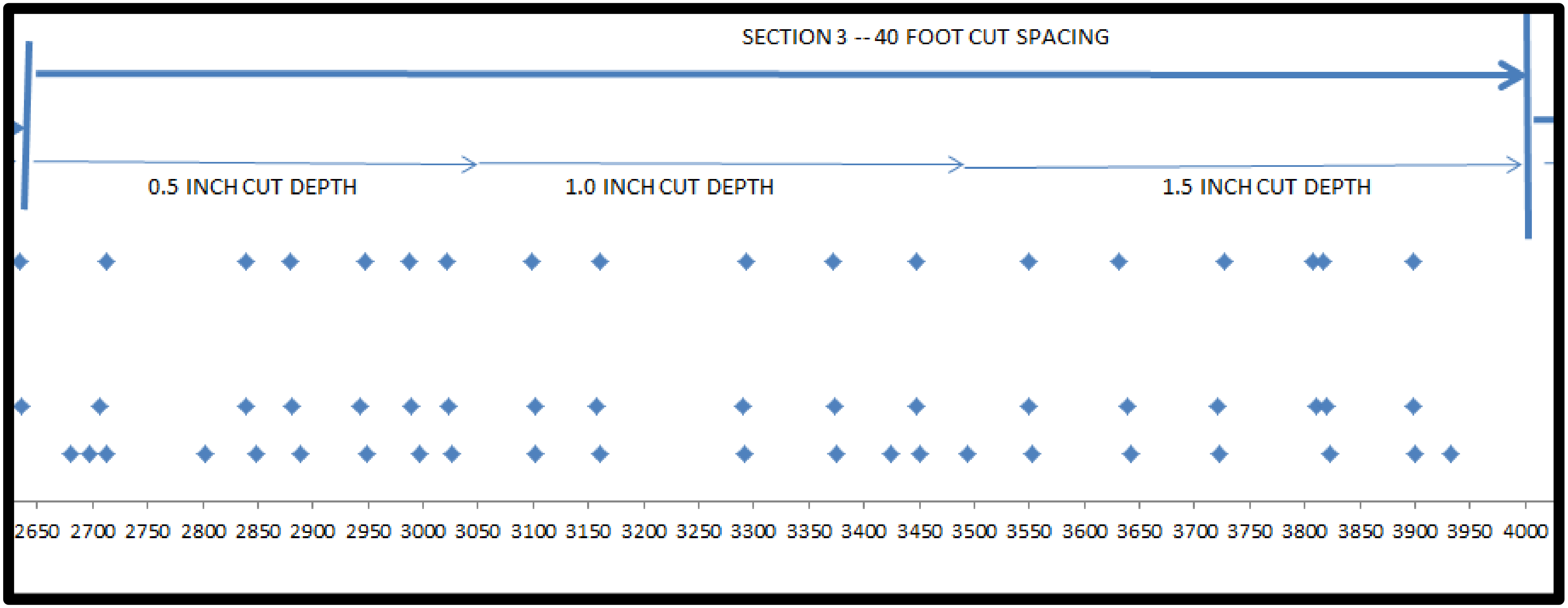


Appendix C1. Experimental Subsection 1 crack map — the Control Section



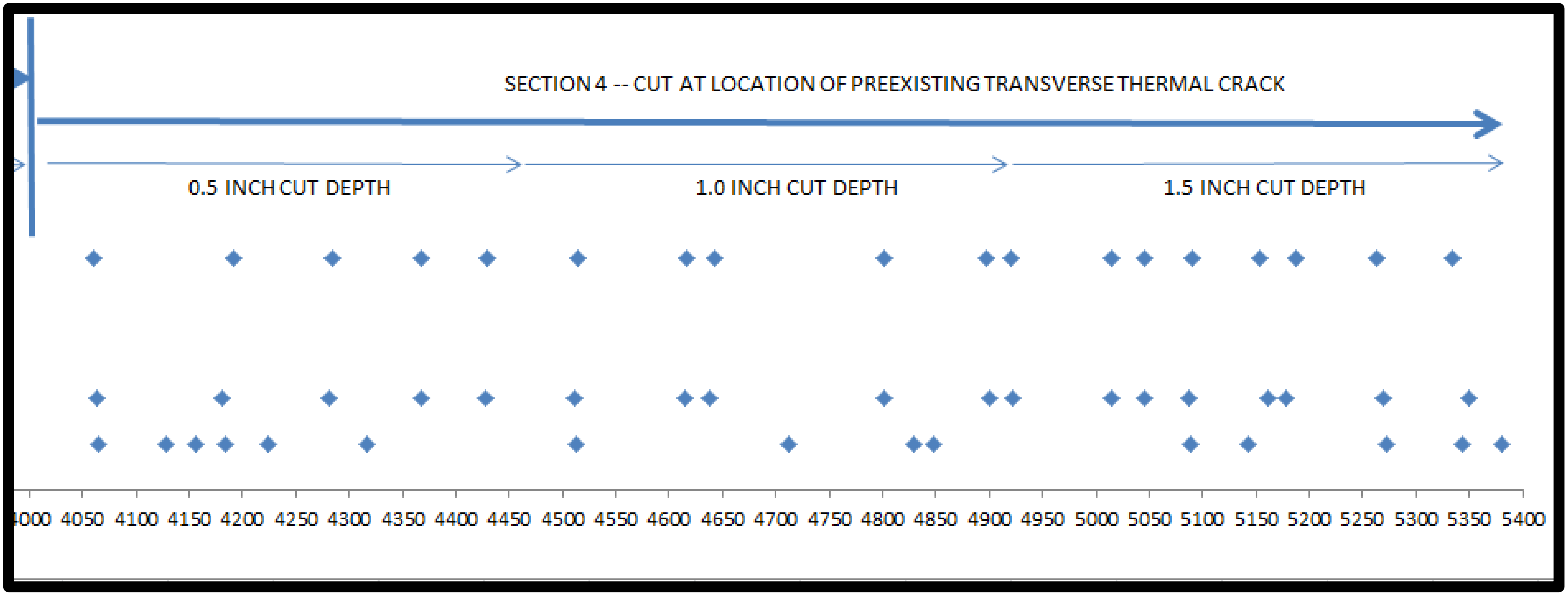
Note: See page Appendix C1 for explanation of points

Appendix C2. Experimental Subsection 2 crack map



Note: See page Appendix C1 for explanation of points

Appendix C3. Experimental Subsection 3 crack map



Note: See page Appendix C1 for explanation of points

Appendix C4. Experimental Subsection 4 crack map

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